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Development of Control Algorithm and a Simulation Tool for Self-Assembly of Microsystems Based on Swarm Technology

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DEVELOPMENT OF CONTROL ALGORITHM AND A SIMULATION TOOL FOR SELF-ASSEMBLY OF MICROSYSTEMS BASED ON SWARM TECHNOLOGY

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CERTIFICATE OF APPROVAL

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ABSTRACT

"Chunxel" Technology is a novel concept of constructing 3-dimensional structures using a group of intelligent, autonomous, and cooperating micro robots. Chunxels are small robotic modules, cubical in shape, which are immersed in a tank containing a viscous fluid. The chunxels are propelled by the electromagnetic forces created by passing direct current through a set of large coils placed on each face of the tank and small coils embedded in the micro device. The chunxels follow a set of rules which mimic a swarm behavior and self-assemble in the liquid to form a 3-D structure. Swarm behavior is a dynamic problem and in order to ensure the completion of the task in reasonable time by the swarm it is necessary to have a robust control algorithm and a navigation strategy. The objective of this research was to develop such a control algorithm which when followed would assure the successful completion of the task given to the chunxels. Also in order to understand the dynamics of the swarm and verify the control strategy it was important to simulate this process so that the chunxels can be programmed accordingly. This thesis presents the development of the control algorithm for the swarm and the simulation tool used to test this algorithm. The final phase of this thesis concentrates on optimizing the various parameters of the chunxel device that affect the motion of the chunxel inside the tank.

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1. INTRODUCTION

The need to quickly construct three-dimensional color displays and objects from computer-generated designs is extensive. Designers using personal computers or workstations commonly emulate three-dimensional objects by using computer graphics software to create sophisticated shading and coloring schemes. Rapid Prototyping technologies can be employed to construct permanent three-dimensional objects by building shapes from specialized materials. Alternatively, specialized imaging techniques can quickly produce color stereoscopic images that are quite realistic, but these have no solid substance and often require a special viewing apparatus. The combination of two emerging technologies, swarms technology and Microsystems technology, offers a unique opportunity to quickly create color three-dimensional objects and displays. "Construction of three dimensional objects and displays using swarms of intelligent microsystems" is a concept for a new device based on emerging swarm and micro-system technologies. This concept is referred as the "Chunxel Technology".

Swarm technology, following the social insect metaphor is concerned with the collective behavior of large number of intelligent autonomous agents, with limited capability to perceive, reason and act, that are capable of performing sophisticated tasks, such as food harvesting and nest building (Stiebitz P.H., Carrano A.L., Alejandro B.E., 2002). Swarm research attempts to understand and mimic this behavior of social insects to come up with alternative robotic solutions. Swarm engineering requires generation of swarm conditions and fabrication of a set of behaviors that satisfy the given swarm condition. This swarm condition, when satisfied, will guide the generation of a swarm of agents, which is capable of carrying out the desired actions. No specific method is formulated for the generation of swarm condition and it is largely problem dependent.[1]

Microsystems technologies are those focused on the development of highly integrated mechanical, electrical, optical, chemical, biological and computing systems whose

[1] (http://www.jisan.org/research/swarm/swarm.intro.html).

functional elements are sub-millimeter in size (Stiebitz P.H., Carrano A.L., Alejandro B.E., 2002).

Integrating the above two technologies gives rise to the chunxel technology that consists of intelligent, autonomous, cooperating micro robots, known as chunxels, and a display housing, which is a cubical tank containing a liquid carrier media in which the chunxels are neutrally buoyant (Stiebitz P.H., Carrano A.L., Alejandro B.E., 2002). The chunxels can self-propel and self navigate through a viscous fluid. Within this environment, chunxels will be able to self-assemble to form different pre-defined three-dimensional shapes (Stiebitz P.H., Carrano A.L., Alejandro B.E., 2002).

This technology has numerous applications in the areas of three-dimensional real-time displays, rapid prototyping, entertainment special effects, games and toys. Other uses of the chunxels technology are in production of three-dimensional maps for military or exhibition purposes and 3D organs for medical training (Stiebitz P.H., Carrano A.L., Alejandro B.E., 2002).

Various possible fields of application have been mentioned for this invention. The chunxel technology has been conceptualized with rapid prototyping in mind. CAD files would be transferred to a control station, sending information to chunxels. The chunxels would then assemble into a prototype of the item described in the CAD files.

An as yet unexplored area for chunxel research and application is that chunxels can be used not only to generate static structures but also can be used to show dynamic behavior. This dynamic behavior can be used in animating displays for advertising and also in entertainment industry. Another serious application of dynamic chunxel behavior is carrying out tasks that individual chunxels will fail to complete. In this case the synergetic swarm behavior can be effectively utilized.

2. BACKGROUND

In August 2001, an invention disclosure entitled " Construction of three dimensional objects and displays using swarms of intelligent Microsystems" was filed with Rochester Institute of Technology's office of Grants, contracts and Intellectual Property. The work for this research, which was referred to as "Chunxel Technology" was already initiated in summer of 2001 utilizing Kate Gleason College of Engineering (KGCOE) research funds granted to the Laboratory for Autonomous and Cooperative Microsystems (LACOMS). LACOMS is a multi-disciplinary research effort focused on the development and integration of swarm technologies with Microsystems technologies.

The whole chunxel system will consist of the following major components:

- A system of intelligent, mobile, partially autonomous Microsystems (referred to as Chunxels) that can alter their color and self assemble into pre-defined desired three-dimensional color shapes.
- A display housing containing liquid carrier media that provides buoyancy for the chunxels.
- Software that translates standard CAD files into chunxel assembly instructions.
- Control software that co-ordinates the assembly of chunxels.
- A communication system that allows a computer to send and receive information to and from the chunxels.
- A means to transfer energy to the chunxels (Stiebitz P.H., Carrano A.L., Alejandro B.E., 2002).

Chunxels are propelled by forces created by magnetic fields due to a set of large coils placed in the environment and powered by direct current, and small coils embedded in the device also powered by direct current. Figure 1 shows the chunxel device prototype along with a chunxel placed in the center of the tank. The display housing of the current prototype is a 6-inch cubical tank made of acrylic walls and surrounded by six external coils, one on each of its faces. The chunxels are propelled by magnetic force of attraction generated by passing direct current through these large set of coils and small coils embedded inside the chunxels. In general, the propulsion force exerted on the chunxel is proportional to the radius, current, and number of windings of the external coils, the radius, current and number of windings of the internal coil, the distance between the two coils and the permeability of the liquid medium.

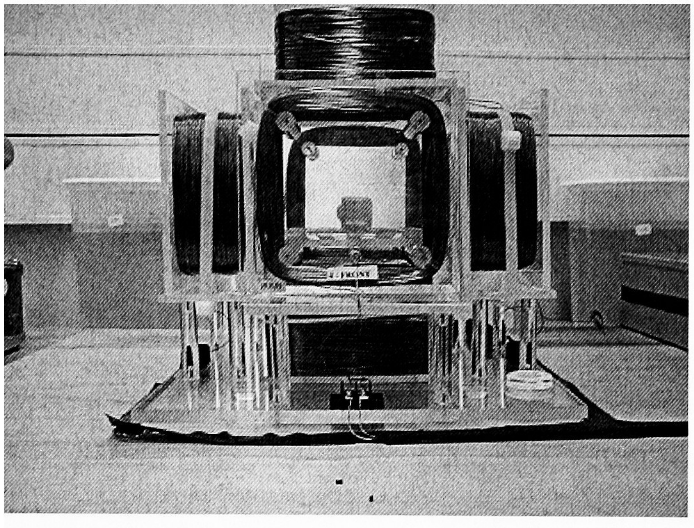

Figure 1: Chunxel Device (Prototype)

The development of working prototypes is envisioned to be in four stages. The first generation chunxels are 25mm cubes. This chunxel has a novel six-sided shape with three out-dented and three in-dented surfaces that have been developed to promote the self-alignment of the groups (Stiebitz P.H. 2002). Each side of the first generation chunxels is manufactured by injection molding such that size identical pieces could be assembled in any combination of in-dents and out-dents. Figure 2 shows the current generation 25 mm chunxels. Each chunxel consists of a means for position sensing, a means for attaching itself to other chunxels, and a communication system capable of sending and receiving information from the system control and a computing system (Stiebitz P.H., Carrano A.L., Alejandro B.E., 2002). The second generation will be 12mm cubes also manufactured by conventional machining and molding techniques, while the third generation will begin making the transition to MEMS (Micro Electro Mechanical Systems) fabrication techniques reducing the size to 4 mm and finally shrinking it to 1mm in the fourth generation (Stiebitz P.H., Carrano A.L., Alejandro B.E., 2002).

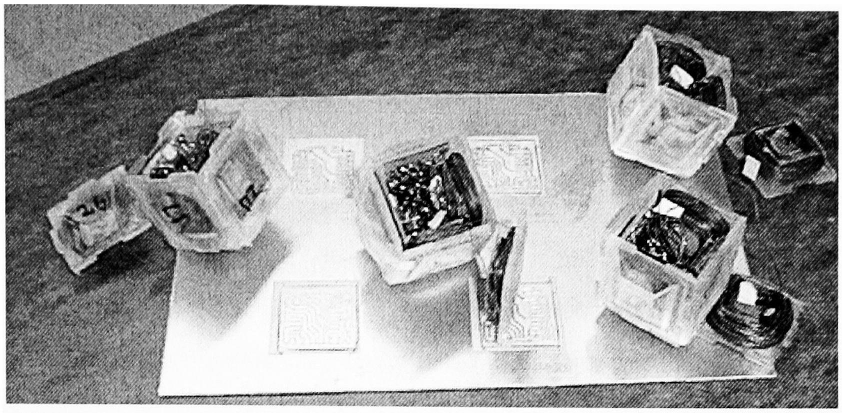

Figure 2: Current Generation Chunxels

In the next chapter the technical details of the chunxel device are discussed. These details are for the current generation of the chunxel device. The first prototype run was conducted using the same specification as mentioned in the next chapter. The tests conducted on the chunxel device showed that the communication and propulsion aspects of the design performed as expected thus giving impetus to the chunxel project.

3. TECHNICAL DETAILS OF THE CHUNXEL DEVICE

This section presents the hardware and the control details of the chunxel device. The understanding of the hardware details of the chunxel and the control system used to propel the chunxels in the fluid environment will help in discussing the scope of this research.

Each chunxel has two major operational modes as follows:
The propulsion mode: the external and internal coils will be used as electromagnets; and
The positioning mode: the external coils will be used as a generator of magnetic field.

Propulsion:
For the propulsion purpose, a 48V DC power supply is used to generate a magnetic force and drive the coil. Each external coil will have an intermittent DC signal. The chunxel could then use one of the internal coils as an electromagnet to move along the magnetic field created by the external coil. Power from the front or back coil gives a movement along the x-direction, power from the west or east coil gives a y movement and north and south a z movement. The power supply is a 48 VDC power supply (Yvanoff, Marie 2002).

Positioning:
For the positioning purpose, an AC power supply is used to drive the coil. This second way to power the external coils will generate a time varying magnetic field inside the tank, which induces an emf in the internal chunxel coils. As this chunxel comes closer to the coil powered, the emf induced in the three internal coils increases. These coils are orthogonal and represent the X, Y and Z-axis of the chunxel (Yvanoff, Marie 2002).

Communications between a system controller and the chunxels is achieved by the pulsing the external coils in a structured fashion. By counting the induced emf pulses on the chunxel coil, a series of pulses can be decoded to extract a message transmitted by a host computer, or even other chunxels.

3.1. External coils driving sequence

To drive the six external coils, an AC and DC sequence is used, the AC for the positioning sensing and the DC for propulsion, as described in the previous section. The DC energizes the external coils in the sequence West, North, Back, East, South, Forward. The three orthogonal coils within the chunxel are optionally energized in concert with the external coils to produce thrust sequentially in the six directions. In the second operational mode, the chunxel's spatial position is determined by applying an alternating current to the external coils sequentially, and then sensing the induced emf in the chunxel coils (power is not applied to the chunxel coil in this mode). The control driving sequence and the time delays are shown in Figure 3 and Figure 4 respectively (Yvanoff, Marie 2002).

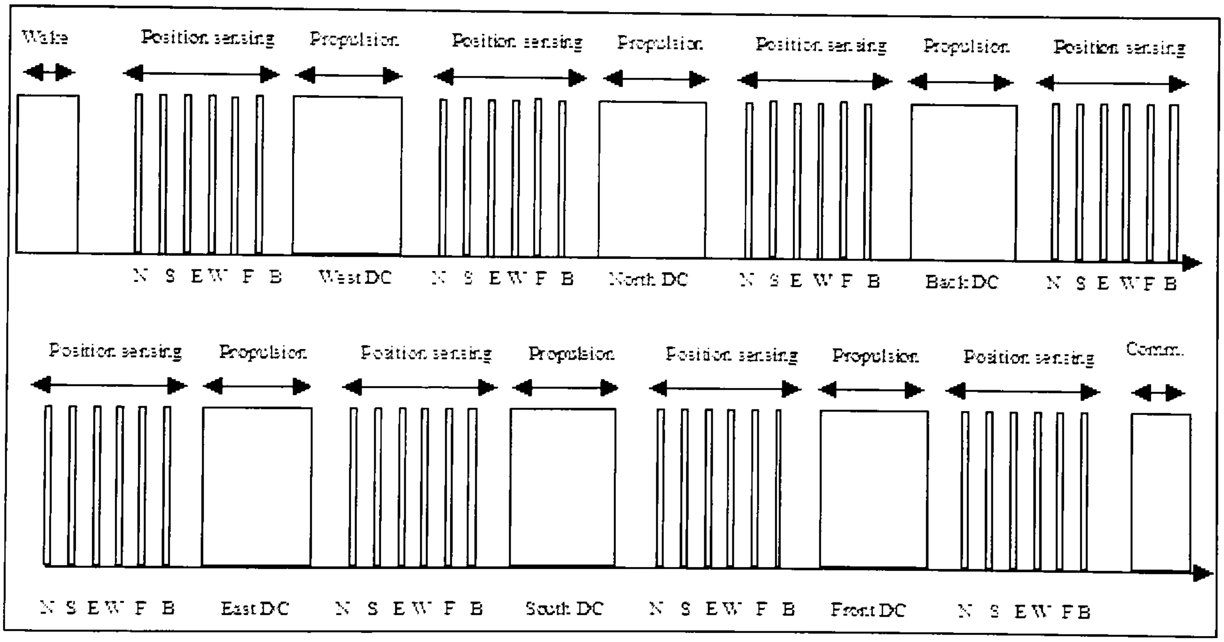

Figure 3: Control Driving Sequence

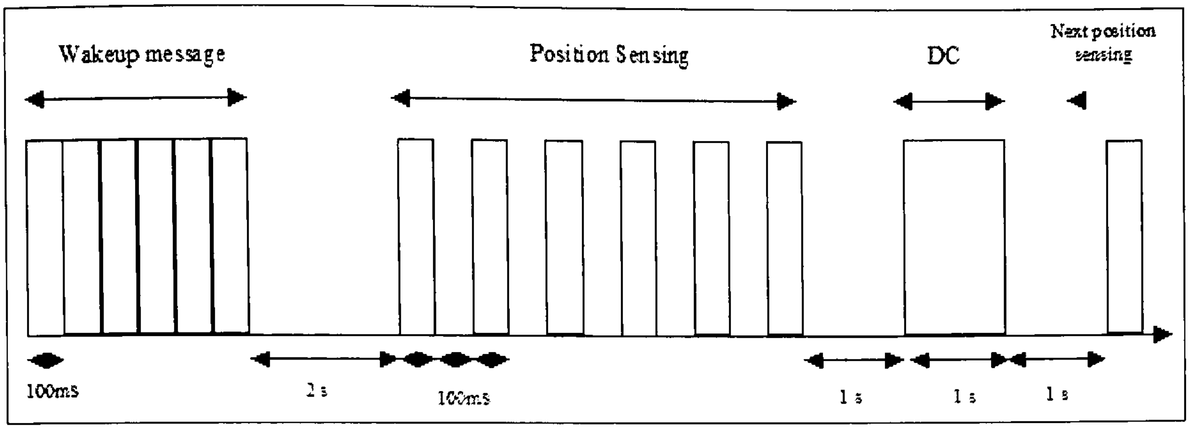

Figure 4: Timing Delay

3.2. Robot assembly and construction

Inside the chunxel, two 19mm squares of single layer circuit boards and batteries constitute the electrical components. One of the batteries is used to drive the internal coils when they are used as electromagnets. Two other batteries are used to supply current to a micro controller and signal amplifiers. Each of three indented faces of the cube contains the three small internal coils while the two out-dented faces contain the circuit boards and the small batteries, and on the third one there is a battery used to drive the coils. Design detail and construction of the chunxels is shown in Figure 5. (Yvanoff, Marie 2002)

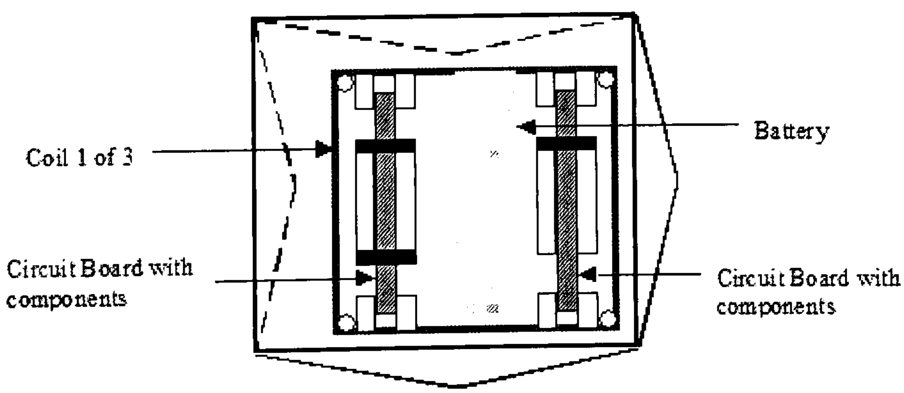

Figure 5: Schematic Diagram of the Chunxel

3.3. Results of Initial Trial

The initial trial of the chunxel device was conducted in March/August 2002. The goal of this demonstration was for a proof of concept for the chunxel device. It turned out that the chunxels were behaving as expected. Some of the observations that were made during this run are as follows:

- The wakeup signal waked up the chunxels;
- The chunxel timing scheme was synchronized with the driving sequence;
- The speed of the chunxels during the propulsion was as expected;
- The chunxel seemed to move around the target area but never stopped; and
- One of the chunxel located near the corner of the tank spun around.

As it turned out, the concept of chunxel device was working properly and proved that it was a good design.

4. STATEMENT OF PROBLEM

In chunxel technology the behavior of the chunxel is primarily based on the concept of swarms. Swarm engineering has two formal steps. The first involves the generation of a swarm condition. Swarm condition is a set of rules or behaviors, which the individual agents in the swarm must follow in order to form a co-operative structure within the swarm. This is a condition which, when satisfied, will guide the generation of a swarm of agents which is capable of carrying out the desired action or actions. The second step in swarm engineering involves the fabrication of a behavior or set of behaviors that satisfy the given swarm condition. Also the generation of swarm behavior is a dynamic problem and in order to ensure the completion of the task in reasonable time by the swarm, it is imperative to develop a robust navigation strategy.

The collective behaviors of components in a dynamic system (like a swarm behavior) can influence the environment and when this occurs the constraints on the components in a system are not fixed, and thus attempts to analyze the system, must provide an ongoing mutable parameterization of the environment (A Tutorial Introduction to Swarm). Thus, in order to understand the dynamics of the swarm system under a given navigation strategy and test the performance of the algorithm it is important to simulate this process. Simulation is a process of designing a computer model based on some underlying computational logic of a real system and conducting experiments with this simulation model for the purpose of understanding the behavior of the system and evaluating various strategies for the operation of the system.

The swarm behavior is the logic behind the motion of the chunxel. The intelligence given to the chunxel is nothing but a set of swarm rules and behavior in order to decide the next direction in which it has to move. But the actual physical motion of the chunxel inside the liquid media is dependant on parameters like the cycle time, radius and number of turns of the external and internal coil and also the current carried by these coils. It is important to evaluate the effect of these parameters on the motion of the chunxels inside the display tank. For example, the tests conducted on the actual prototype of the chunxel device showed that the chunxels continuously hunted for their pre-programmed targets. This was believed to be due to a high propulsion force control set point, which is proportional to the radius, current and number of windings of the external and internal chunxel coils (Yvanoff, Marie 2002). In order to build a stable 3D structure it is imperative to minimize hunting. The physical and economical limitations of the existing prototype, and construction of new prototypes, also makes it necessary to develop a simulation tool, which would aid in understanding the effects of the various parameters mentioned above. This testing of algorithms with different values for the physical parameters will help in optimizing the device and come up with optimum values for all the variables that affect the motion of the chunxel so as to reduce the hunting effect and at the same time reduce the time in which the chunxel reaches the target.

The basic problem that was addressed in this research was that of basic navigation and motion control of the individual chunxel units based on swarm behavior. The overall problem included identification of target locations for the chunxels to fill, the broadcast of these target locations to the available chunxels, selection of target location by the individual chunxels, movement to the target location using proportional control scheme and broadcast by the chunxel that the target is occupied.

The most innovative part of this research however was the dynamic behavior of the 3-D structures formed. The chunxels demonstrated collective synergistic behavior to fulfill the swarm condition and complete tasks, which were not possible by individual the chunxels.

Thus the objectives that have to be fulfilled by this research can be summarized as below:

- Development of a 2D simulation tool;
- Development of a navigation strategy for generation of 2D shapes;
- Demonstration of synergistic behavior by developing a control algorithm in the 2D simulation tool;
- Development of a 3D simulation tool; and
- Development of a navigation strategy for generation of 3D structures.

For this reason, the scope of the problem included both static structure generation as well as dynamic structure behavior.

5. LITERATURE REVIEW

This research deals with swarms behavior, multi robot cooperation, navigation strategies, and control algorithms for forming 3-D structures. The creation of artificial swarms has become an interesting topic of research in the last fifteen years. This research finds its roots in the seminal work of Rodney Brooks (Brooks R, 1986), which advocated the creation of simple robots with simple behaviors in the place of robots of complex abstract models and interpreters for intelligent behavior. The method is called *behavior-based control* and has become widely accepted, due to the simplicity of the approach, the flexibility and potential for generalization to learning and the capability of researchers to create swarms of simple behavior based robots capable of carrying out interesting behaviors. Several researchers have proposed interesting methods of creating control algorithms for such simple robots, including learning and evolutionary algorithms (Harvey I., 1994), and work continues on both of these general methods.

Artificial swarm design has thus far been largely along two different lines of design. The first of these is the practical approach (Kelly I., and Keating D., 1996, 1998, 1998, Mataric M., 1995, 1995a, 1997a), in which a particular task is identified and a group of robots is built with the task in mind. This work typically contains multiple iterations of design and redesign of the physical robot and/or its controller to complete the task (Goldberg D., and Mataric M., 1997). The second of these is the theoretical approach in which a task is examined theoretically, and a condition is derived which will yield the global goal. The design of the robots is then an exercise in obtaining robots whose real dynamics matches the desired dynamics, which can take one iteration. The main difference between these is that in the first approach, an understanding of the underlying system dynamics is generated through the building and improvement of various versions of the system, while the second attempts to generate an understanding of these dynamics, and subsequently build robotic systems based on this understanding. In this way, the second approach is more similar to traditional methods in robotics, in which the system dynamics are worked out before the generation of a robot. The use of this approach in swarm robotics would seem to provide validation of the swarm-based approach to system design, indicating that these methods are not unrelated to work done on individual robots carrying out sophisticated tasks with high precision. Rather, they may be seen as an extension of those methods to tasks requiring a smaller degree of individual precision.Many studies have been undertaken using the practical approach to swarm construction. Among these are studies investigating navigation and exploration tasks, rudimentary construction tasks, task allocation studies, and communication studies.

The closest known research is reported by Mitre Corporation (www.jisan.org) in the area of self-assembly of Microsystems and Nanosystems. The objective of the research was to determine if a large number of mobile micro robots, the size of a grain of a salt, could self-assemble under distributed control in order to fabricate more complex structures (qtd. in Stiebitz P.H., Carrano A.L., Alejandro B.E., 2002). The Intelligent Autonomous Systems Engineering Laboratory at the University of West England has undertaken studies similar to MITRE. O.E. Holland and C.R. Melhuish discuss swarming simulations conducted under the following minimalist assumptions: a beacon in the environment transmits an omni directional signal, agents have the ability to sense that a signal is above a threshold but cannot discern direction, agents are propelled by repeated impulses, the direction of motion is in the direction of stronger signal except for a small random perturbations and the environment consists of a circular two dimensional space. Simulations of Multiple types of field attenuation, noise and signal following rules produced conditions in which agents very efficiently converge to the signal source, even when the source is moving (qtd. in Stiebitz P.H., Carrano A.L., Alejandro B.E., 2002).

Murata et al discuss the development of identical robots capable of forming arbitrary, large scale, complex, three-dimensional forms and dynamic mechanical structures. Their approach utilized cubic shells couples by rotating mechanical joints. These couplings, along with the imbedded intelligence, allow the cubes to climb over one another to create new forms (qtd. in Stiebitz P.H., Carrano A.L., Alejandro B.E., 2002). Chirikhjian et al have also examined the problem of self-reconfiguration of collection of identical mechatronic modular robots that have the ability to connect, disconnect and climb over adjacent modules without the outside help (qtd. in Stiebitz P.H., Carrano A.L., Alejandro B.E., 2002). In "Self-Organizing Collective Robots with Morphogenesis in a Vertical

Plane" Kazuo Hosokawa et al have presented a novel concept of self-organizing collective robots with morphogenesis in a vertical plane. It is potentially applicable to autonomous mobile robots. For physical reconfiguration of a swarm of robots against gravity, new types of mechanisms and control strategies are proposed and demonstrated.

Coates et al in their paper "The Use of Cellular Automata to Explore Bottom Up Architecture Rules," discuss the use of three-dimensional cellular automata to construct three-dimensional shapes. Cellular automata are entities that have been given a set of internal and external rules by which they form spatial relationships with other cellular automata. In this way, it is thought possible to provide each entity with sufficient local information to guide its participation in the construction of the overall form (qtd. in Stiebitz P.H., Carrano A.L., Alejandro B.E., 2002). Antonio Sgorbissa and Ronald C. Arkin have showed how robots navigating within an unknown environment with local communication capabilities can cooperate by helping each other to achieve their own goals. Cohen reports on a mapping and navigation task in which swarm of robots spreads itself in a maze, and collectively maps the terrain. The map is detailed enough to allow an agent to travel from a point in the map to any other point in the map in a minimum amount of time, while using minimal individual processing, and taking advantage of an elegant communication scheme (Cohen W., 1996).

There are other publications, which propose different control strategies for problem specific tasks to be solved by swarm robotics. G. Dudek et al present taxonomy to the different ways in which a collection of autonomous robotic agents can be structured (Dudek G., 1993). Gage details the design of a multiple robot system for mine detection. This work focuses on illustrating the benefits in time and correctness of coordinated and communicating multiple robot detection schemes. The use of communication and coordination is found to be a serious advantage over the lack of it, in terms both of detection speed, correctness, and cost/success ratio (Gage D., 1995). A method based on artificial physics and derived from artificial life is gaining increasing support. This method purports to create a dynamic set of equations capable of being followed by given agents in a system, which produces a desired behavior of the swarm. The advantage of such an approach is that these equations may be completely solved, yielding the stationary states of the system, and the modes of evolution of the system. As long as the robots are capable of following the dynamic equations of motion, the method will provide the desired behavior (Spears W., and Gordon D., 1999).

The most interesting and closely related research is Touchable User Interface Using Self Movable Robotic Modules. This device (Patent: 6,243,622) consists of a touchable user interface including multiple robotic modules that can "walk" over each other to allow reconfiguration of the interface. Each module preferably includes motive devices as well as connective devices communication between the modules and a control unit that sends commands to the interface, thereby enabling its reconfiguration. Space filling robotic polyhedral modules (Patent: 6,233,503) consists of a movable robotic module including a framework defining a set of vertex elements, a set of edge elements, or a set of face elements, with the framework substantially shaped to permit face centered cubic packing. Each module includes a pivot mechanism on its framework to permit rotation of the framework with respect to other movable robotic modules. A power unit supplies operational power to each module, the power being used for rotation of the module, sensor and/or a control unit connected to the pivot mechanism and/or the power unit to control rotation of the framework (Yim et al).

There is much research done in the area of swarms and Microsystems as discussed above, but there are no known disclosures of the system of the type being studied and researched in this thesis. The major source of information comes from the various papers, projects and experiments conducted on chunxel technology itself. In "N-Body Simulations of Microsystems Self-Assembly" a paper directly related to the chunxel project, J.C. Tillet and P.H. Stiebitz have discussed the equations of motion, the transition between various stages of motion, and an efficient method of detecting collisions among spherical Microsystems, which are capable of self-navigation and self-propulsion in 3-D space. This paper also discusses the various control strategies viz. Directed, Cooperative and Autonomous. This thesis is a part of an extension of this paper and compliments the construction of hardware prototypes for the chunxel technology. Tillet Jason C, and

Stiebitz P.H. also found that the collision avoidance and post collision recovery plays an extremely critical role in the ability of the population to efficiently self-assemble. It is also stated that because of the limited computing power of the chunxels, development of parsimonious control algorithms is required for their navigation and self-assembly. In order to improve the probability of completing the 3-Dimensional geometry in a reasonable amount of time increasingly intricate navigation algorithm must be explored.

6. METHODOLOGY

This research dealt primarily with the development of a robust control algorithm for the chunxels to successfully complete the three dimensional geometry. As earlier stated the control algorithm was verified using a simulation tool. The development of a control algorithm and the simulation tool was a simultaneous and iterative process. The research was divided into five phases. This distribution of work helped in clearly defining the goals and objectives for each phase and a timeline within which the research was to be completed.

The five phases for the completion of the research are as follows:

Phase 1 - Development of a Two Dimensional Simulation Tool:

This was the first step towards building a full fledge 3-D simulation tool for the chunxel project. The motion of the chunxels in two axes viz. X and Y was studied with the help of this program. The program was developed using Java 2 SDK. The basic swarm rule of occupying the nearest available target was incorporated in this program, which the chunxels would follow thus beginning the process of developing a control algorithm using swarms behavior. This phase also took into account the physical details of the system like collision detection and minimal programming effort of avoiding the collisions was used so that a fair representation of the actual system could be obtained.

Phase 2 - Demonstration of Synergetic behavior using 2-D Simulation Tool:

The second phase was to demonstrate the synergetic behavior of the chunxels by giving a set of targets to the chunxels in order to retrieve a dead chunxel from a random position in the tank and pushing it upward above the surface of liquid inside the tank. This phase was carried out to help understand the dynamic nature of the chunxels while working in tandem with each other. The already developed 2-D simulation tool was used to observe this behavior.

Phase 3 - Development of a Control Algorithm and a 3-D Simulation Tool:

The 2-D simulation logic was extended to incorporate a third axes viz, thus moving the simulation into the realms of 3-D space. Java 3D API was used to program the 3-D simulation tool. The control algorithm and simulation program was simultaneously developed. Basic swarms behavior, method for reducing hunting of targets, was incorporated in the program in this phase. Other programming details like collision detection, application of electro-magnetic force equations, physical phenomena of buoyancy, and fluid dynamics of the chunxel inside the liquid medium, were also taken into consideration in this phase thus developing a simulation model representing the actual chunxel device for experimentation purposes. The final step in the development of the simulation program was designing an interface. This interface helped in dynamically changing the various parameters of the model. The various parameters considered were the radius, current, turns in internal and external coils, mass of the chunxel, density of the liquid medium, and the cycle time for energizing of the external coils.

Phase 4 - Verification of the 3-D Simulation Tool:

Phase 4 dealt with verifying the program and checking its validity. Data pertaining to the propulsion force experienced by the chunxel at various locations in the tank, the average velocity of the chunxel inside the tank, the drag forces generated were compared to the actual data collected during the prototype runs of the chunxel device and to the calculated values from the physical equations present in the literature. Also visual inspection was one of the tools used to observe the behavior of the chunxels and see if compares to the expected motion as seen in the prototype run. This was the most important phase of the research as it was the foundation for obtaining reliable results from the experimentations that were conducted in the last phase of this research.

Phase 5 - Experimentation and Optimization using the 3-D Simulation Tool:

This phase was critical for the future of the "Chunxel" Technology. Experiments were carried out in this phase, using the simulation tool, with different configurations of the hardware parameters to find out an optimal configuration for the next generation chunxel device.

6.1. Phase 1: Development of a Two Dimensional Simulation Tool

The main objective to be achieved by the end of the first phase of research was to develop a basic framework for the final three dimensional simulation tool for the chunxel device. A two-dimensional simulation tool was developed as the first step in the research so that the basic functionalities of the chunxel could be visualized and checked. Also, this 2D program was the building block upon which the complete structure of the 3D simulation tool was based upon. The 3D simulation tool was, in a sense, an extension of the basic 2D program with more functionalities and physical phenomenon incorporated in it. Here it is important to mention that the 2D simulation tool was a method to evaluate the behavior of the chunxel under the proposed control strategies and not to evaluate the physical parameters of the device. In the 2D simulation the chunxel moves only in four directions viz. North, South, East, and West, unlike the actual device where the chunxel is free to move in the six directions proposed to be North, South, East, West, Forward and Backward. The chunxel coordinates are thus denoted using only x and y coordinates in the X and Y Axes respectively.

6.1.1. Java and 2D Simulation Tool

The 2D program was written in Java 2 (Version 1.4.1 SDK), as an applet. In the later stages of this research the program was designed to run as a Java application because of the need to read and write files from the local machine arose, which will be discussed in the Phase 4 of this research. Java applets are not designed to read or write files, because as a general rule, Java applets run under a "better safe than sorry" security model. Applets cannot do any of the following:

- They cannot read or write files in the user's file system.
- They cannot communicate with an Internet site other than the one that served the web page that included the applet.
- They cannot run any programs in the reader's system.

- They cannot load programs stored on the user's system, such as executable programs and shared libraries.

Java applications have none of the restrictions in place for applets. They take the full advantage of Java's capabilities.

The 2D simulation program was designed using the java classes that support graphical features. The 2D program comprised of displaying small squares that represented the chunxels in the applet window and animate these squares, i.e. move them on the screen depending on the control logic proposed in the research. Animation in Java is accomplished by using the Abstract Windowing Toolkit (AWT), Swing and the Threads class in the java.lang.package.

It will be helpful at this stage to understand a little bit about the Java coordinate system that is used by the AWT and Swing packages. It is imperative to know how graphical objects like rectangles that are used to represent the chunxels in this 2D program, are displayed on the screen. The other thing to consider here is how the java coordinate system is related to the directional conventions used in the chunxel device.

6.1.2. Java coordinate system & directional conventions

Java's coordinate system used pixels as its unit of measure. The origin coordinate 0,0 is in the upper-left corner of the Applet window. The value of x coordinates increases to the right of 0,0 and y coordinates increases in a downward direction. This differs from other drawing systems in which the 0,0 origin is at the lower left and y values increases in an upward direction. All pixel values are integers; decimal numbers cannot be used to display something between integer values. Hence the motion of the chunxel is proposed to be increments or decrements of one pixel unit.

The chunxels are shown on the screen by using fillRect() method in Java that draws solid rectangles. The fillRect() method takes four arguments:

- The x and y coordinates of the rectangle's top left corner; thus the x and y positions of the chunxels and the targets are the top left corner of the squares.
- The width of the rectangle (Chunxel width = 10 pixel units)
- The height of the rectangle (Chunxel height = 10 pixel units)

The four directions that are used in the chunxel device are shown in the Figure 6 along with the java coordinate system. The North direction of the chunxel device is directed upwards towards the origin, and the other directions are relative to this North direction. According to the above convention and the Java coordinate system, a movement in North is affected by subtracting one pixel unit from the y coordinate of the current chunxel position, the South movement by adding one pixel unit to the y coordinate. Similarly the West motion is brought about by subtracting one pixel unit from the x coordinate and East motion by adding one pixel unit to the x coordinate of the chunxel position.

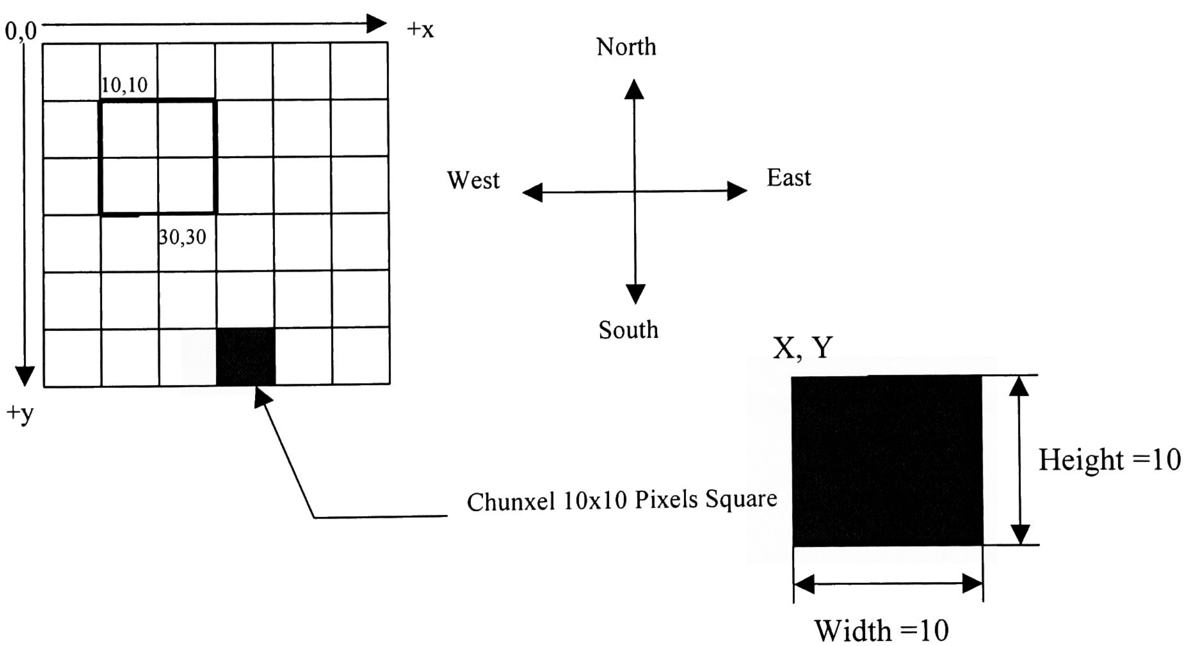

Figure 6: Java coordinate system & Chunxel Dimensions in Java 2D

6.1.3. Basic Control Algorithm

The essence of the chunxel device is to form a 3D geometry by giving a set of coordinates or targets which the chunxels should occupy, thus forming the proposed 3D structure. In order to occupy the specific targets, the chunxels have to move within the tank in specific directions. Thus simple control logic for this motion is as follows:

1. Identifying the target to be occupied;
2. Moving towards the target; and
3. Occupying the target.

For n number of targets with n number of chunxels inside the tank, the chunxels will select the target nearest to its current position. Since the chunxels are autonomous agents, all the chunxels inside the tank are given information about all the target positions. Based on the "Nearest Target" rule the chunxel will identify the target, which it desires to occupy. The distance between the current chunxel position and the target is given by

$$\mathbf{Dist(C_nT_n) = Sqrt(\,(c_nx+t_nx)^2 + (c_ny+t_ny)^2\,)}$$

Where,

c_n is the chunxel with identification number n,

t_n is the target with identification number n, and

x and y are the coordinates of the chunxel and target.

In the Java source code the square root is not considered, since the squared values of the distances are directly compared with each other. This is done in order to reduce the computational load on the program. The distances between each chunxel and all the targets are compared and the target, which is at the least distance from the chunxel under consideration, is selected by that chunxel.

There can be a situation where two chunxels can select the same target location; in such a situation, the chunxel that reaches the target first, occupies the target. Once a target is occupied, the occupied target and the chunxel that occupies the target are "Locked". This means that the chunxel that occupies the target and the occupied target are no longer available. This can be better understood while going in the details of the control logic flow, which is discussed later in the chapter. In designing the simulation tool, the targets and initial chunxel positions were randomly generated within the tank or specific target coordinates were supplied within the program. In either case it was necessary to initialize the target locations and initial chunxel positions. This was done by creating two arrays with two dimensions and n elements, one array for the chunxels and the other for the targets; n is the number of targets and chunxels to be initialized. It is assumed in this program that the number of chunxels initialized is equal to the number targets to be achieved. The first dimension is the reference number or identification number of the target and the chunxel. The second dimension stores the x and y coordinates of the corresponding chunxel or target. Thus the array can be represented in a matrix shown in Table 1.

Table 1: 2D Array for storing Chunxel Information in Java

1st Dimension	2nd Dimension			
Identification #	**[0]**	**[1]**	**[2]**	**[n]**
[1]	x	y	--	--
[2]	x	y	--	--
[n]	x	y	--	--

Adding the above control strategies to the simple control logic loop gives the basic control algorithm that the chunxels and the chunxel device have to follow.

Basic control Algorithm:

Step 1 *Initialize target positions;*

Step 2 *"Unlock" all targets. i.e. non-occupied;*

Step 3 *Initialize chunxels positions;*

Step 4 *"Free" all chunxels. i.e. chunxels are not occupying any target position and free to move;*

Step 5 *Check if any of the targets are occupied;*

Step 6 *If target is occupied; "Lock" the target and the chunxel occupying that target;*

Step 7 *If all targets are occupied goto step 18;*

Step 8 *Broadcast the "Unlocked" targets to the "Free" chunxels;*

Step 9 *Select target locations to be achieved by the chunxel based on the "Nearest Target" rule;*

Step 10 *Decide the directions for the individual chunxels to move in towards the selected target;*

Step 11 *Store the above information in the chunxel memory;*

Step 12 *Energize north coil;*

Step 13 *Energize east coil;*

Step 14 *Energize south coil;*

Step 15 *Energize west coil;*

Step 16 *Goto step 6; and*

Step 17 *End simulation.*

The direction to be pursued by the chunxel is decided by the relative position of the chunxel and the target. If the chunxel is to the left of the target the chunxel has to move in the East direction and if it is to the right of the target then it as to move in the west direction. Similarly, if the chunxel is below the target, it has to move in north direction and if it is above the target then it has to move south. Mathematically,

If,

$cx - tx > 0 \Rightarrow$ *chunxel is to the right, Move west*

$cx - tx < 0 \Rightarrow$ *chunxel is to the left, move east*

$cy - ty > 0 \Rightarrow$ *chunxel is below, move north*

$cy - ty < 0 \Rightarrow$ *chunxel is above, move south*

6.1.4. Collision Detection

In any simulation of a physical phenomenon or physical model it is necessary to see that two objects do not overlap or interpenetrate. Collision detection is a system of determining whether two or more objects collide. Collision detection is a computational geometry problem. To make any simulation of a physical model realistic collision detection is essential.

Most collision detection methods usually deal with the temporary positions reflecting where the objects are about to be. If a collision occurs with the temporary positions, the movement of the objects could be reconsidered. A simple logic for collision detection is:

1) Future position calculation;
2) Collision detection; and
3) Collision handling.

The logic governing object motion would proceed in a loop like this:

Entity_oldPosition = Entity_currentPosition

Modify Entity_currentPosition depending upon the control logic

If Entity collides then Entity_curentPosition = Entity_oldPosition

In simple words the logic can be explained as follows:

- Save the current position in a temporary variable;
- Calculate the new position and save it as current position; and
- If at this current position the entity collides with any other entity then change the current position to the value stored in the temporary variable.

In the above algorithm for collision detection, when objects collide, they are moved back to the previous position, because if those were the safe spots for the objects a moment ago, they will probably be still safe. But there are complications in the method that we chose: for example, when an object is moved back to its starting position, care has to be taken that it is really still safe; if not (because an object might have moved in that space in the meantime), then the offending object must be moved back to its own starting position. The worst that can happen is that all the objects have to be reverted back to their own starting points. This is an extremely slow way because it involves significant iteration (Blow Jonathan, 1997)

The other way to overcome the problem of collision detection in the case of chunxel 2D simulation is collision avoidance. The principle is to move only those chunxels, which do not have any potential collision, taking place with any other chunxel. It is also very easy to predict the collision in the case of chunxel simulation because all the chunxel are moving in the same direction or not moving at all at any point of time in the simulation. This logic is more robust than the former and much faster. Also since collision response is not a factor to be considered in the 2D simulation program, the collision avoidance strategy is better suited for this application.

Either collision detection or collision avoidance, there has to be a way to predict whether the objects interpenetrate or overlap each other. This is achieved by using the "Bounding box" approach. A simple way to check whether the bounding boxes intersect is "if the tops are higher than the bottoms and the lefts are 'lefter' than the rights, then the boxes intersect." (Magarshak Greg, 2000). Figure 7 depicts the bounding box approach.

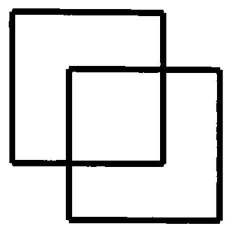

Figure 7: Bounding Box Collision Detection

A method for the chunxel collision detection was developed. This method checks for future collisions that may take place and correspondingly modifies the position of the chunxel under consideration. The collision detection or avoidance algorithm is as follows:

Step 1 *Take the chunxel identification number as an argument for the detection method;*

Step 2 *Check the direction in which the chunxel is moving;*

Step 3 *If chunxel moving in north or south direction goto step 5;*

Step 4 *If chunxel moving in east or west direction goto step 6;*

Step 5 *Moving north or south: check if any other chunxel position is between the colliding ranges.*

This can be achieved by

a) Checking if the x-coordinate of any other chunxel lies between the (x-coordinate of the current chunxel – 9 pixel units) and (x-coordinate of the current chunxel + 9 pixel units) AND

b) Checking if the y-coordinate of any other chunxel is equal to 10 pixel units from the y-coordinate of the current chunxel.

Step 6 *Moving east or west: check if any other chunxel position is between the colliding ranges.*

This can be achieved by

a) Checking if the y-coordinate of any other chunxel lies between the (y-coordinate of the current chunxel – 9 pixel units) and (y-coordinate of the current chunxel + 9 pixel units) AND

b) Checking if the x-coordinate of any other chunxel is equal to 10 pixel units from the x-coordinate of the current chunxel.

Step 7 *If collision is not detected advance the position of the chunxel by one unit in the pre-determined direction else do not change the position of the chunxel.*

6.1.5. Proportional Motion

The first prototype run showed that the chunxels continuously oscillate about the target position. This is because of the gravity and buoyancy effects, collisions and also the constant cycle time that even after being locked to a specific target the chunxels keep on hunting for the target position. To minimize this "Hunting of the Target" a "Proportional Motion" method is implemented. Although in the 2D simulation program, the hunting effect cannot be observed since only integer values are accepted for the coordinate by Java even then the proportional motion logic was employed so that it could help in extending the same logic to the 3D simulation program.

The logic behind proportional motion is to take bigger steps when the target is far way from the current chunxel position and as the chunxel approaches the target go on taking smaller and smaller steps. In an actual device this can be achieved by turning ON the internal coil for a certain percentage of the cycle time. Thus by controlling the Time ON for the internal coil inside the chunxel, the time for which the magnetic force of propulsion that acts on the chunxel can be controlled. In this way the displacement of the chunxel can be made smaller as it approaches the target. If the distance between the chunxel and target is greater than the size of the chunxel then the chunxel takes multiple steps towards the target, else it takes only one step. This distance was termed as the "threshold distance." The initial algorithm was adjusted so that each coil is energized for multiple times and each time the distance between the target and current chunxel position is checked, and if the distance is greater than ten pixel units, then the position of the chunxel is updated by one pixel unit towards the target. Figure 8 makes it easier to understand the principle of proportional motion method. Since the 2D simulation tool does not take into consideration the cycle time, and actual propulsion force arbitrary values were selected for the threshold distance, and the number of maximum steps that the chunxel takes if the distance between the chunxel and the target is less than the threshold distance.

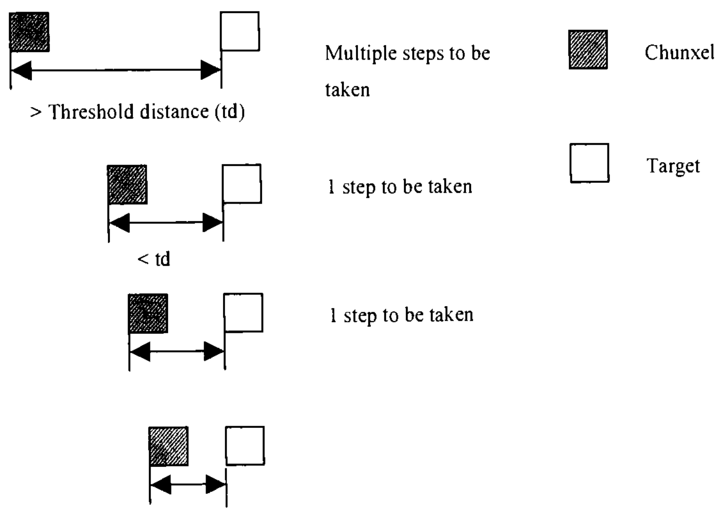

Figure 8: Proportional Feedback Motion in 2D Simulation Tool

The logic that was used to implement proportional motion can be expressed in the following algorithm:

Step 1 *For any directional coil that is energized: create a loop count = 0*

Step 2 *If count = 0 goto step 4*

Step 3 *If count > 0 goto step 5*

Step 4 *Advance the chunxel position by one pixel unit in the determined direction. Change the position of the chunxel only if there is no collision detected for the future position.*

Step 5 *If the difference between the target position and current chunxel position is greater than 10 pixels unit after pixel units then only advance the position of the chunxel by one unit in the determined direction. Change the position of the chunxel only if there is no collision detected for the future position.*

Step 6 *If count < 6 then goto step 2 else goto step 7*

Step 7 End: energizing of the coil. Move to the next coil energizing sequence.

Combining the basic control algorithm with the collision detection and proportional feedback motion algorithms gives the basic framework of the 2D simulation program. The basic flow of the Java program is as shown in Figure 9. The detailed flow of instructions and conditional looping of the program in shown in Appendix A in the form of a flowchart.

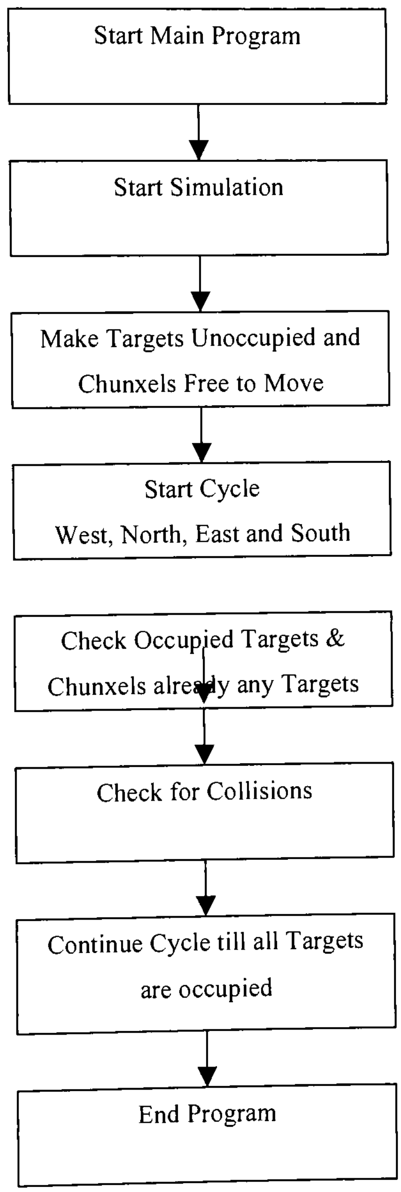

Figure 9: Block Diagram for General flow of 2D Simulation Program

6.2. Phase 2: Demonstration of Synergistic behavior using 2-D Simulation Tool

One of the most innovative parts of this research was, not only the generation of static structures, but also the dynamic behavior of those structures. The proposed approach at the beginning of the research was to form a static structure and the ability to demonstrate a dynamic behavior for the structure. The basic approach to navigation and control was to implement a swarm style behavior that would allow all chunxels to stand on a common non-hierarchical platform with one another, behave autonomously yet with collective goals and synergistic functionality. This phase of research was dedicated solely to demonstrate that the chunxels could exhibit collective synergistic behavior and complete tasks together that could not be completed as individuals.

One such task is "building of a chunxel platform with an individual chunxel atop the platform. Once the structure is built the next step is to raise the individual chunxel up above the level of tank medium." This behavior would be impossible for an individual chunxel, but can be accomplished by the group working together.

An algorithm was developed in this phase to accomplish this task. During this phase, a strategy was also developed to overcome deadlock situations for the chunxels while moving towards their respective targets. The deadlock situation is defined when a chunxel cannot reach its target location due to the presence of some obstruction, generally another chunxel that is stationary on its achieved target. A search sub-routine was developed to find an alternative path towards the target to be reached.

6.2.1. Synergistic behavior algorithm

The above-mentioned task of lifting an individual chunxel above the liquid level was demonstrated by developing the synergistic behavior algorithm. In order to lift a chunxel above the liquid medium inside the tank the following steps were followed:

- Determination of the individual chunxel that has to be lifted above liquid medium.

- Determination of the targets in order to from a platform beneath that chunxel.
- Broadcasting of the targets to the available chunxels inside the tank.
- Once the platform has been created, broadcasting a desired delta movement for each chunxel.

Figure 10 below shows the simulation and the formation of the platform and the movement of the chunxels in order to lift a chunxel above the liquid medium.

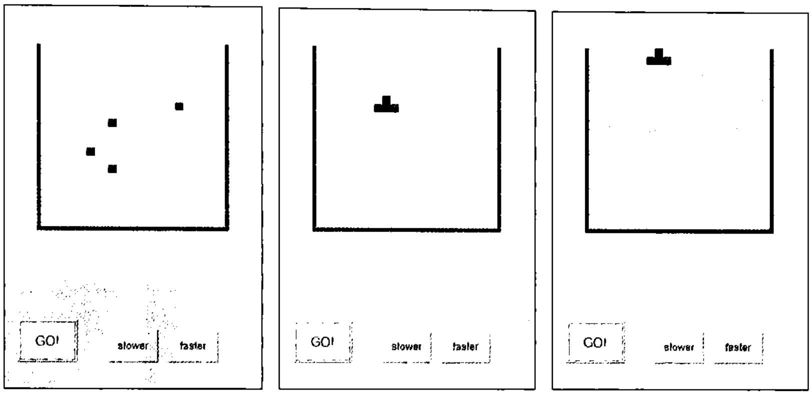

Figure 10: 2D Simulation Tool Screenshots

The incremental delta movement is given by looping the program in such a way that once one delta movement is achieved the next set of delta targets is given to the chunxels. This is repeated until the last set of targets or the co-ordinates of the targets where the individual chunxel is above the liquid level is achieved.

The formation of a platform is fairly easy when the chunxel to be lifted is away from the walls of the tanks. But in the scenario where the chunxel to be lifted is close to the walls the platform cannot be made. In such special case scenarios the chunxel to be lifted is pulled away from the other chunxels and then when it is sufficiently away from the walls and enough room is available to form the platform beneath the original algorithm is run which lifts the chunxel above the liquid level as in normal cases.

Thus an addition to the original algorithm is made. Before broadcasting the targets, the system sees the position of the chunxel which is to be lifted and if it is sufficiently away from the walls of the tanks in order to facilitate the formation of the platform runs the normal algorithm else it goes into a different sub-routine. In this sub-routine, the dead chunxel to be lifted is first pulled away from the tank. For this a different set of targets is broadcasted and then the normal algorithm is resumed.

The strategy followed to pull the chunxel away from the wall is shown in the figures below. The first case in Figure 11 is when the chunxel is either near the right or left walls. In second case shown in Figure 12, the dead chunxel to be lifted is near the base of the tank.

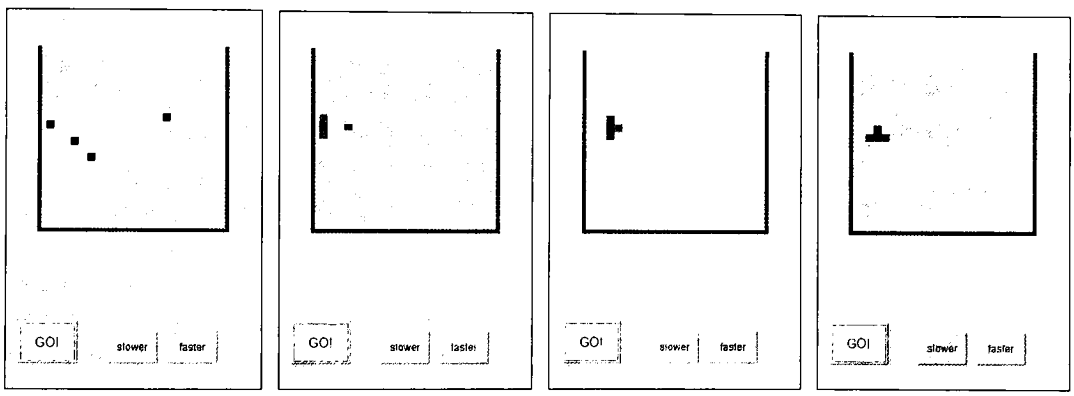

Figure 11: Dead Chunxel Retrieval from near the Tank Walls

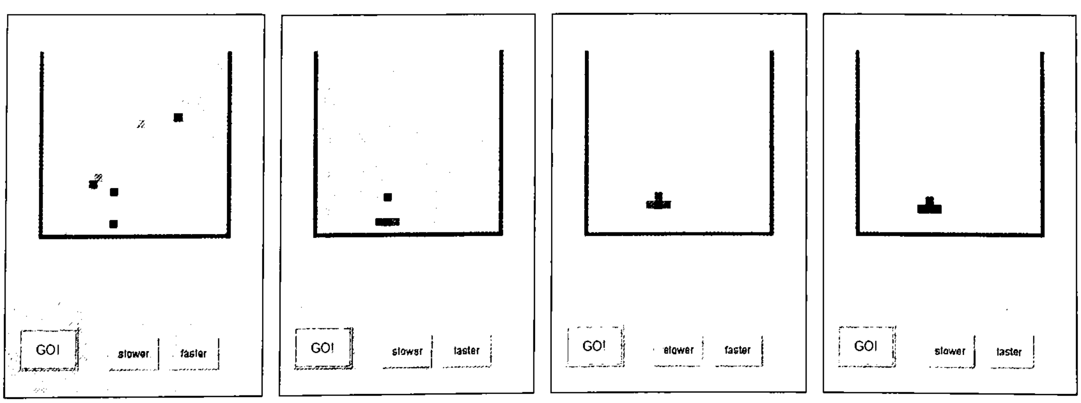

Figure 12: Dead Chunxel Retrieval from near the Base of the Tank

6.2.2. Search path algorithm

After the collision detection was incorporated in the simulation tool it was observed that the chunxels which were already on their specified target came in between the way of other chunxels which were still moving towards their specified targets. This situation, which is typically called as a deadlock situation, had to be overcome in order to assure the completion of all the targets. This was achieved by developing a search path sub-routine. In simpler words, whenever a moving chunxel encountered any obstacle in its path and was unable to move for a certain number of cycles, the chunxel would follow a sub-routine which would help it to find a different path towards its decided target. There were two scenarios that presented themselves while the observational runs were made to lift the dead chunxel above the liquid medium.

Scene 1: the moving chunxel was trapped in one direction because of another chunxel that was on its target, or because of the dead chunxel was in its way (see Figure 13).

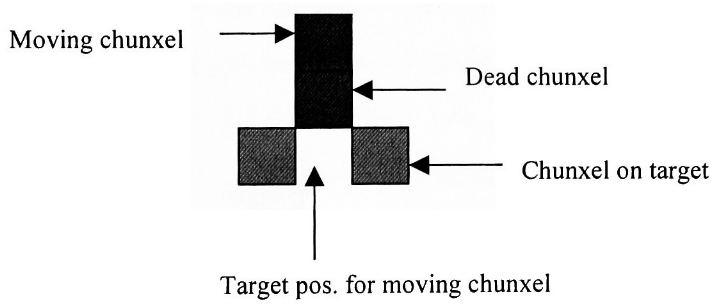

Figure 13: Moving Chunxel Trapped in One Direction

Scene 2: the moving chunxel was trapped in two directions because of the dead chunxel on one side and another chunxel on its target (see Figure 14).

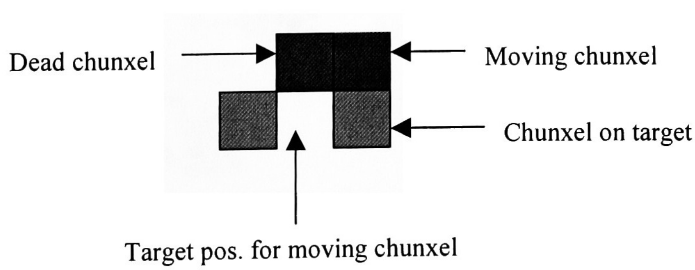

Figure 14: Moving Chunxel Trapped in Two Directions

The search path algorithm or sub-routine is initialized whenever the chunxel moving towards the target encounters obstacles in its path. The detection of obstacles is known to the chunxel not by physical detection but rather when the chunxel is unable to change its position for more than two cycles of coil energizing. Once the sub-routine is started, the chunxel is oblivious of the target location but has to follow a certain set of steps before it is again available to achieve its target. The sub-routine is a simple movement of the chunxel in a certain direction where it is free to move. A rather different approach had been devised here to get out of a deadlock situation. The chunxel when trapped will try to move in a clockwise direction in order to overcome the obstacle. For the two cases shown above two different solutions are presented in the subroutine along with the explanation of the clockwise direction motion of the chunxel to move out of the deadlock situation.

Sub-routine 1: when the chunxel is trapped in only one direction.
Consider the chunxel is trapped in south direction.
Step 1: to move 12 units in the East direction. The movement is fixed to 12 units in order to ascertain that the trapped chunxel clears the obstacle, as the obstacle here is assumed to be another chunxel with sides 10 units (see Figure 15).

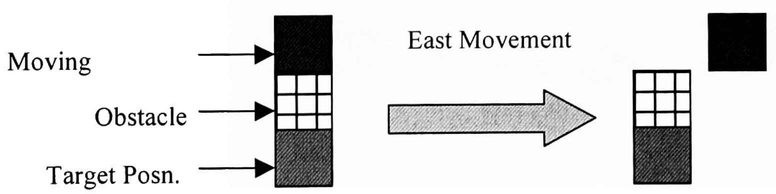

Figure 15: Sub-routine to Circumvent an Obstacle in Y-axis (Step 1)

Step 2: to move 12 units in the South direction (see Figure 16).

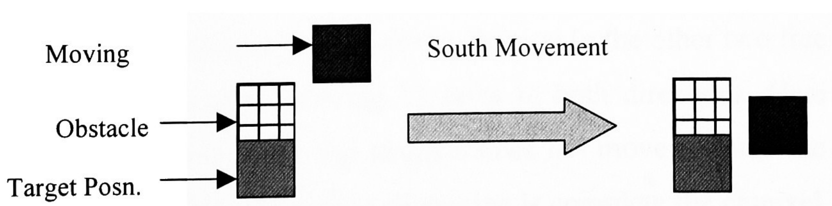

Figure 16: Sub-routine to Circumvent an Obstacle in Y-axis (Step 2)

Generalizing the above algorithm, it can be said that the second step of the sub-routine is always for the chunxel to move in a direction in which it is trapped and depending upon this direction, the first step is to give a clockwise direction to the chunxel. For example, if the chunxel is trapped in the East direction, Figure 17 and Figure 18 show how the chunxel will come out of the deadlock situation and also how the clockwise motion is decided.

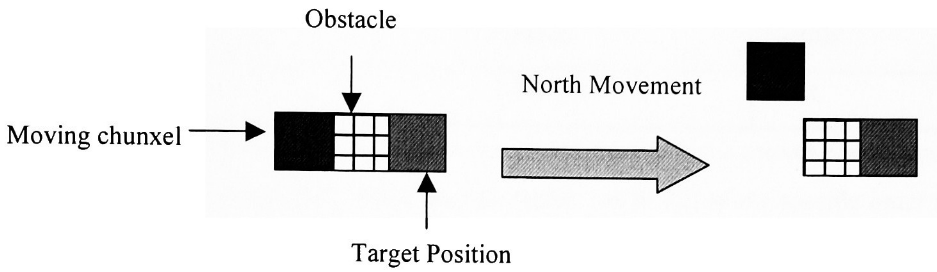

Figure 17: Sub-routine to Circumvent an Obstacle in X-axis (Step 1)

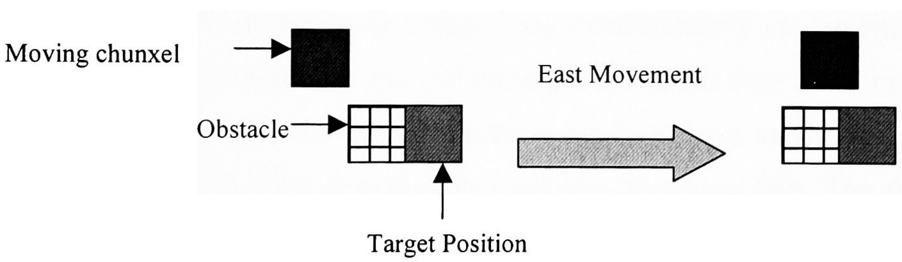

Figure 18: Sub-routine to Circumvent an Obstacle in X-axis (Step 2)

Sub-routine 2: When the chunxel is trapped in two directions at the same time.

Even when the chunxel is trapped in two directions a similar approach has been taken to find an alternate path. A clockwise motion of the chunxel in the other two free directions is made, one direction at each time, moving 12 units in both directions. Here again when chunxel is following the sub-routine, the chunxel does not move towards the target but is oblivious of the target position. Once the sub-routine is complete the chunxel waits for the target broadcast at resumes it movement in the direction of the target co-ordinates.

A general set of rules that the sub-routine follows when the chunxel is trapped in two directions is shown in Table 2.

Table 2: Rules for Search Path Algorithm

Rule #	Trapped Directions* (Combination)	First Movement	Second Movement
1	North, West	South	West
2	North, East	West	North
3	South, West	East	South
4	South, East	North	East

*The chunxel is simultaneously trapped in both directions, thus the order in this column is not important only the combination of direction is important. While the sub-routine has to follow the specific order for getting out of the deadlock by following the first movement first and then the second movement, both 12 units.

6.2.3. Shortcomings of the search path algorithm

This algorithm fails when the chunxel is trapped in more than two directions. This was usually observed when the dead chunxel to be retrieved was near the walls of the tank and the moving chunxel was trapped in three directions simultaneously viz, on one side by the dead chunxel, on the other side by a chunxel on target and in the third direction by the tank wall. One of the possible solutions for this problem can be to have an alternate sub-routine that will be initialized if the first algorithm in clockwise directions fails. The alternate sub-routine will have a counter clockwise search method. This will increase the chances of trapped chunxel to achieve its target position in the given problem for lifting the dead chunxel above the liquid surface inside the tank.

6.3. Phase 3: Development of a Control Algorithm and a 3-D Simulation Tool

The objective of this research was to develop a simulation program, which could represent the actual Chunxel device. In order to achieve this it was imperative to move from 2-Dimensional simulation to 3-Dimensional simulation program. This was accomplished in Phase 3 of this research. The 3-D program was in a way a extension of the 2-D logic but there were many other additions to the simulation tool which are mentioned below:

- Animation and frame rate (to make it more realistic simulation).
- Actual magnetic forces experienced by the chunxel inside the tank.
- The motion of the chunxels not just in Java units but measured in actual SI units calculated by the acceleration experienced by the chunxel and the velocity imparted to the chunxel by the magnetic forces caused due to the energized coils.
- Other forces experienced by the chunxels like the Drag Force, Buoyant Force, etc.
- The proportional feedback motion with a definite mathematical equation instead of just simple Java unit steps as implemented in the 2D simulation program.
- Introduction of coasting of chunxel after the propulsion force has ceased to exist. The coasting is caused due to the Kinetic energy present in the chunxel.

It was also in this phase that the user interface for the simulation tool was designed which aided in changing the various parameters that affect the motion of the chunxel inside the tank. The user interface was designed using the Swing components in Java. Also along with the interface a main menu was designed which helps the program to setup the initial conditions of the chunxel device viz use.

- Type of run (Experimental / Normal).
- The tank size.
- Number of chunxels inside the tank.
- Generation of targets (random / user defined targets).
- Generation of initial chunxel position (random / user defined chunxel co-ordinates).
- Etc.

The above menu is discussed in detail later in this chapter, which deals with the user interface creation and options.

6.3.1. Introduction to Java3D

A brief understanding of Java 3D would help in understanding how the different force equations and displacement of the chunxel are implemented. The co-ordinate axes in Java3D are same as Java2D with the exception that there is a third axes viz. Z-axis, which is present that is normal to the viewing screen. The Figure 19 shows the java 3D co-ordinate axes.

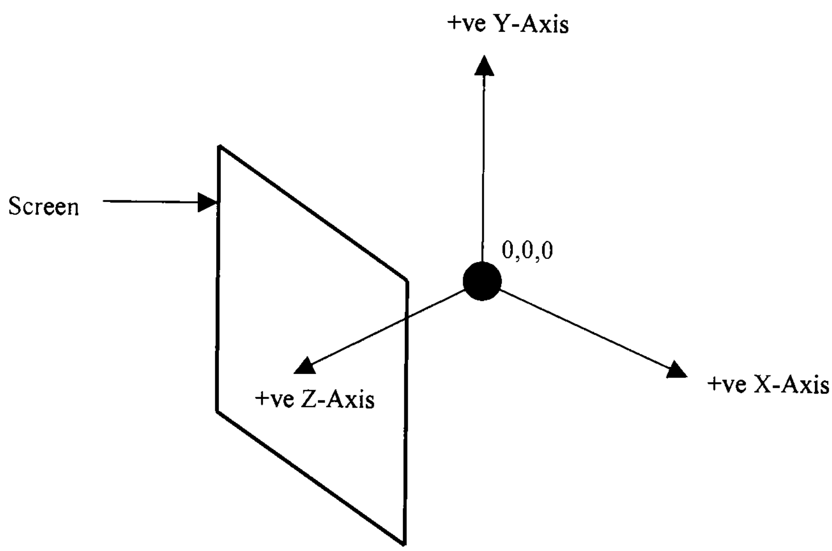

Figure 19: Java 3D Co-ordinate System

The co-ordinates for these axes are float values with distance measured in meters. Thus all the equations that were implemented in this simulation program are in SI units.

6.3.2. Force equations

The chunxels are completely immersed in the liquid medium inside the tank. The propulsion of these chunxels is brought about by the magnetic force of attracting between the external coils surrounding the tank and the internal coils. Since the chunxels are immersed in the liquid there is a buoyant force, which acts upon the chunxels. Also the motion caused by the magnetic forces gives rise to a drag force which is like a frictional force between the surface of the chunxel and the liquid medium. Thus there are three major forces that act upon the chunxel viz.

1. The magnetic force of attraction
2. The drag force while the chunxel is in motion, and
3. The buoyant force.

A brief explanation of these forces in given below along with the equations that were used to represent these forces in the simulation program.

Magnetic force of attraction:

For the propulsion purpose, a DC power supply is used to generate a magnetic force and drive the coil. Each external coil has an intermittent dc signal. The chunxel then uses one of the internal coils as an electromagnet to move along the magnetic field created by the external coil. The propulsion force is given by the following first order equation.

$$\boxed{Fp = \frac{3 * mu * N_1 * N_2 * I_1 * I_2 * R_1^2 * R_2^2 * Z * \cos\phi}{2 * (R_1^2 + Z^2)^{5/2}}}$$

Equation 1: Magnetic Force of Attraction

Where,

Fp = Propulsion force in Newton

mu = permeability of the medium $=1.25*10^{-6}$

N_1 = number of turns in the external coil

N_2 = number of turns in the internal coil

I_1 = current in the external coil in Amps

I_2 = current in the external coil in Amps

R_1 = radius of the external coil in meters

R_2 = radius of the internal coil in meters

Z = distance of the internal coil from the external coil in meters

ϕ = angle between the major axis of the external coil and the internal coil

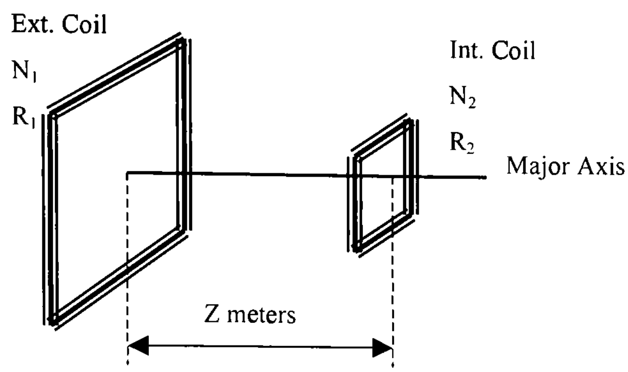

Figure 20: Calculation of Magnetic Force of Attraction

Calculation of Cos N:

The propulsion force is the maximum when the chunxel or the internal coil is on the major axis of the external coil. As the internal coil moves away from the major axis the force of attraction between the external and the internal coil decreases. This decreases in the proportional force is proportional to the cos factor included in the force equation. The cos factor is calculated in the flowing manner:

Consider the internal coil at a distance of z units from the energized external coil on the XY plane. The internal coil is at a distance of x units from the major axis of this coil in x direction and y units from the major axis in the y direction. A diagrammatic representation of this is shown in Figure 21.

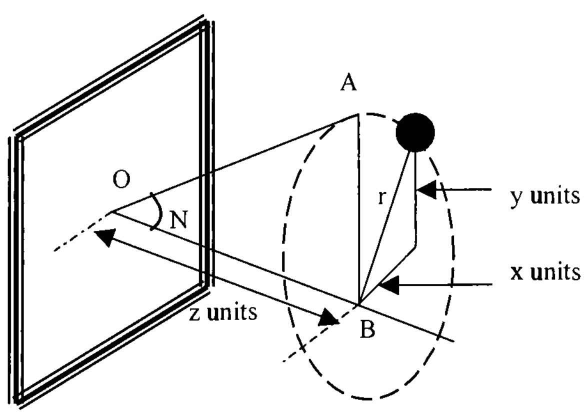

Figure 21: Calculation of Cos factor

r is the radius of the circle formed by the coordinate of the internal coil which is at x and y units from the major axis of the XY coil. Every point at this radius will experience the same magnetic force created by the XY coil. Thus,

$$r^2 = x^2 + y^2$$

Therefore, in the triangle AOB, Point A will experience the same force of attraction because point A lies on the same circle of radius r.

$l(AB) = r$ units

$l(OB) = z$ units

Therefore, $l(OA) = \text{sqrt}\,(r^2 + z^2)$

$\cos N = z / \text{sqrt}\,(r^2 + z^2)$

Therefore,

$$\boxed{\text{Cos } N = z/ \text{sqrt}\,(x^2 + y^2 + z^2)}$$

Equation 2: Cos Factor Equation

Drag force:

Drag is a mechanical force. It is generated by the interaction and contact of a solid body with a fluid (liquid or gas). It is not generated by a force field, in the sense of a gravitational field or an electromagnetic field, where one object can affect another object without being in physical contact. For drag to be generated, the solid body must be in contact with the fluid. If there is no fluid, there is no drag. Drag is generated by the difference in velocity between the solid object and the fluid. There must be motion between the object and the fluid. If there is no motion, there is no drag. The direction of the drag force is always opposite the direction of the body's velocity. The drag force is given by,

$$\boxed{Fd = 1/2 * Cd * v2 * rho * Area}$$

Equation 3: Drag Force

Where,

Fd = Drag force in Newton

Cd = Coefficient of Drag = 0.8 for a cube[2]

v = velocity of the body in the fluid/liquid medium. SI: m/s

rho = density of liquid. SI: kg/m^3

Area = cross-sectional area perpendicular to the flow / motion of the body. SI: m2

Thus the total force acting on the chunxel when it propelled by the magnetic force of attraction between the external and internal energized coils is:

$$\boxed{Ft = Fp - Fd}$$

Equation 4: Effective Propulsion Force

Where,

Ft = total propulsion force in Newton.

Fp = propulsion force cause by the magnetic flux in Newton.

Fd = drag force in Newton.

Buoyant force:

A completely submerged body displaces a volume of liquid equal to its own volume. Experience also tell us that when an object is submerged, it appear lighter in weight; the water buoys it up, pushed upward, partially supporting it somehow. Archimedes' Buoyancy Principle asserts that "An object immersed in a liquid will be lighter by an amount equal to the weight of the fluid it displaces". The upward force exerted by the fluid is known as **buoyant force**.

Buoyant force is caused by gravity acting on the fluid. It has its origin in the pressure difference occurring between the top and bottom of the immersed object, a difference that always exists when pressure varies with depth. Imaging without the object, the same immersed space will be occupied by the same volume of fluid. Buoyant force is give by,

[2] http://www.engineeringtoolbox.com/21_627.html

$$Fb = -m * v * rho * g$$

Equation 5: Buoyant Force

Where,

Fb = buoyant force in Newton

m = mass of the body submerged in the liquid. SI:kg

rho = density of the liquid medium SI: kg/m^3

g = gravitational force = 9.81 m/s^2

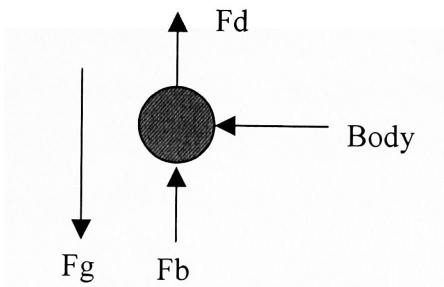

Figure 22: Forces acting on a Body Completely Submerged in a Liquid

The net force on the submerged body is give by,

$$Fnet = Fg + Fd + Fb$$

Equation 6: Net Force on a Submerged Body

Where,

Fg = force due to gravitation

Fd = drag force

Fb = buoyant force

A special case of total force when the chunxel is energized in the downward direction i.e. –ve Y-axis, is given by:

$$Ft = Fp - Fd - Fb$$

Equation 7: Net Force on a Submerged Body moving in the Downward Direction

When the chunxel is energized in the upward direction i.e. +ve Y-axis, the buoyant force adds to the propulsion force and the total force is given by,

$$\boxed{Ft = Fp - Fd + Fb}$$

Equation 8: Net Force on a Submerged Body Moving in the Upward Direction

6.3.3. Animation and displacement of the chunxel

Newton's first law of motion states that "An object at rest tends to stay at rest and an object in motion tends to stay in motion with the same speed and in the same direction unless acted upon by an unbalanced force". This unbalanced forces causes acceleration. Newton's Second Law of Motion is "The net external force *F* acting on a material object is related to the mass *m* of the object and its acceleration *a* by

$$\boxed{F = ma \text{ OR } a = F/m}$$

Equation 9: Force acting on a body in motion

Thus, in the case of the chunxel experiencing the magnetic force of attraction

Acceleration is given by,

$$\boxed{a = Ft/m}$$

Equation 10: Acceleration of the Chunxel

Where,

a = acceleration in m/s^2

Ft = total force in Newton.

m = mass of the chunxel.

The velocity of the chunxel because of this acceleration is then calculated by the equation

$$v_f = v_i + a * dt$$

Equation 11: Velocity of the Chunxel

Where,

v_f = final velocity in m/s

v_i = initial velocity in m/s

a = acceleration in m/s^2

dt = time interval in seconds between subsequent calls for computation.

In order to understand the concept of dt, it is important to understand that some fundamental concepts of animations. Animation is carried out by showing still frames at a certain rate, which gives a perception of movement. This is because the eye retains an image for 1/10th of a second. So if a number of images are flashed at a certain fixed rate we get a feel of motion. This is the basis of all the movies and animations. The same concept is applied here. The acceleration and velocity and thus the displacement of the chunxel are calculated at discrete time intervals and the new displaced positions of the chunxels are shown on the screen. Usually the time interval or the number of still images or frames to be shown to get a continuous animation is 25 or 30 frames per second. This simulation program taking 25 frames per second as the animation speed uses the time interval dt to be 0.04 seconds. Thus the value of time interval is:

$$dt = 0.04 \text{ seconds}$$

The chunxel's position is determined by integrating velocity over time. Euler's method of integration gives the following equation for the displacement,

$$d = d + ((v_{old}+v_{new})/2)*dt)$$

Equation 12: Displacement of the Chunxel

Where,

d = displacement in meters

v_{old} = velocity at dt =0 sec. SI: m/s

V_{new} = velocity after time interval dt =0.04 sec. SI: m/s

dt = time interval between computations = 0.04 sec.

Here it is worth noting the two modes that the simulation program runs in. In the first mode the simulation or the animation is independent of the real time. i.e. the frames are shown depending upon how fast the displacement calculations are made and then the screen is refreshed as soon as the program is ready with the new chunxel positions. In the second mode the simulation is dependant on the clock time and the program tries to refresh the screen every dt seconds. This gives a feel of a very realistic animation with actually 25 frames running per second. These two modes can be toggled during while the simulation is running. With a configuration of less than 150 chunxels the first mode is faster than the second mode because of the CPU speed. Thus in order to run the second mode the program just freezes for a fixed amount of time between two frames.

6.3.4. Proportional Feedback Motion

The propulsion of the chunxel is affected by energizing the external coil and the internal coil at the same time. The time for which the external coil is energized is constant and is called the cycle time. The target location or coordinates are broadcasted before the external coil is energized and depending upon the location of the chunxel it energizes the internal coil in order to move towards the desired location. After the energizing of the coil is completed the targets are broadcasted again and then the chunxel checks its current position and then compares it to the target. If the chunxel is on the target then the chunxel does not energize its internal coil for the next cycle, otherwise it again energizes its coil in order to move towards the target. But when the target is too close the chunxel goes past the target because of the fixed cycle time. Thus in most of the cases the chunxel just oscillates about the mean target position. This is called as "Hunting" of the target. One of the ways to overcome this problem was to have a proportional feedback motion. Wherein, even though the external coil is energized for the fixed amount of cycle time, the chunxel will turn off its internal coil thus stop the propulsion force. This was accomplished by reducing the

Turn ON period of the internal coil as the chunxel gets closer to the target. Hence, the Turn ON period of the internal coil is said to be a function of distance between the current chunxel position, the position of the chunxel at the time the decision of moving towards the target is taken, and the target position. The Time ON for the chunxel is given in percentage of the cycle time. The Figure 23 shows the graphical representation of this relationship.

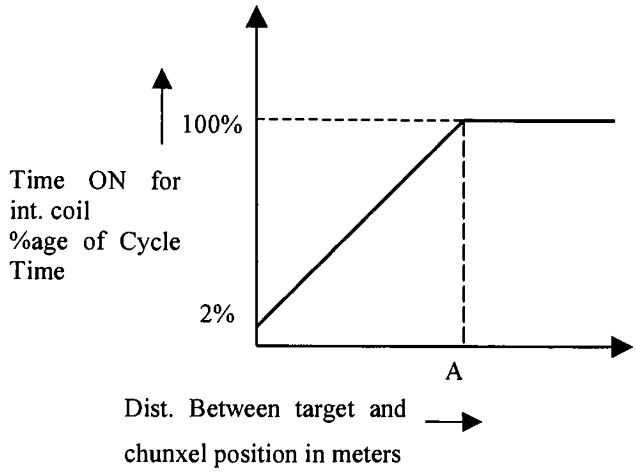

Figure 23: Relationship of Time ON of Internal Coil versus Distance from the Target

The Point A corresponds to a distance of .1 meters and is currently chosen as 20% of the tank size. For all practical purposes the tank size is considered to be not more than .5 meters for the next generation chunxel device. A 2% constant Time ON is considered because if the relationship is made completely linear, theoretically the chunxel will never reach the target, as the Time ON will become infinitesimally smaller as the target distance approaches zero.

6.3.5. Coasting

After the propulsion force stops to act on the chunxel either after the cycle time or after the chunxel switches off its internal coil, the chunxel still goes on moving in the same direction. This is called as "Coasting" and is a result of the Kinetic energy present in the chunxel because of its velocity. As soon as the propulsion force stops this kinetic energy is converted into work, which keeps the chunxel in motion. In absence of the propulsion force the work done by the chunxel is against the drag force or the frictional force caused because of the motion between the fluid and chunxel.

The total force acting on the moving chunxel in absence of the propulsion force is the drag force. Since drag force is opposed to the motion of the chunxel, a negative acceleration is obtained. This negative acceleration decreases the velocity of the chunxel until it finally comes to rest. It was found that the velocity decreases very rapidly during coasting and even though the velocity never actually became zero during the coasting, the displacement caused by such a small velocity was negligible. This helped in reducing the computational load on the program by making the following assumption that the effects of coasting are not considered after the end of the energizing of the next coil in sequence. E.g. if the west coil is energized and the chunxel is moving in the west direction, after the west coil is de-energized the coasting of that chunxel in west direction will begin. The next coil to be energized is north and if the chunxel is moving in the north direction, then the chunxel will simultaneously move in north direction because of the propulsion force and in the west direction because of the coasting. After the north coil is de-energized the coasting in west direction will cease and coasting in north direction will begin along with the motion in the direction of the next energized coil.

6.3.6. User interface

The simulation program developed for the chunxel device has primary two uses; one is two get the experimental data for different values for the hardware parameters and other was to visually the observe the behavior of the chunxels under dynamically changing values. The program has been thus designed keeping these two applications in mind. The actual interface consists of sliders to change the values of parameters and buttons to switch On and Off the different settings like buoyancy, real-time simulation, proportional feedback motion, etc. a screenshot of the application can be seen in Appendix B- Figure 35. the simulation program can be Re-run during its operation with the same configuration it was started with. The initial configuration setup is as shown in Figure 24.

In the experimental run the tank size and the chunxel size has been fixed to 500 mm and 25 mm respectively. The cycle time has to be entered in milliseconds, the radius of the coil in mm and current in amps. The program from a file named exptTargetPos.txt and exptChunxelPos.txt, which is a standard text file, reads the target positions and the initial chunxel position. For the Normal run the tank size and the chunxel size has to be entered by the user in millimeters. In order to input the target positions, the user has to enter the target file name, which has to be windows text file with extension .txt. Similarly for the chunxel position either the user can input coordinate values manually or can tell the program to read the chunxel position from a text file. The number of targets and the number of chunxels should be the same in this simulation program.

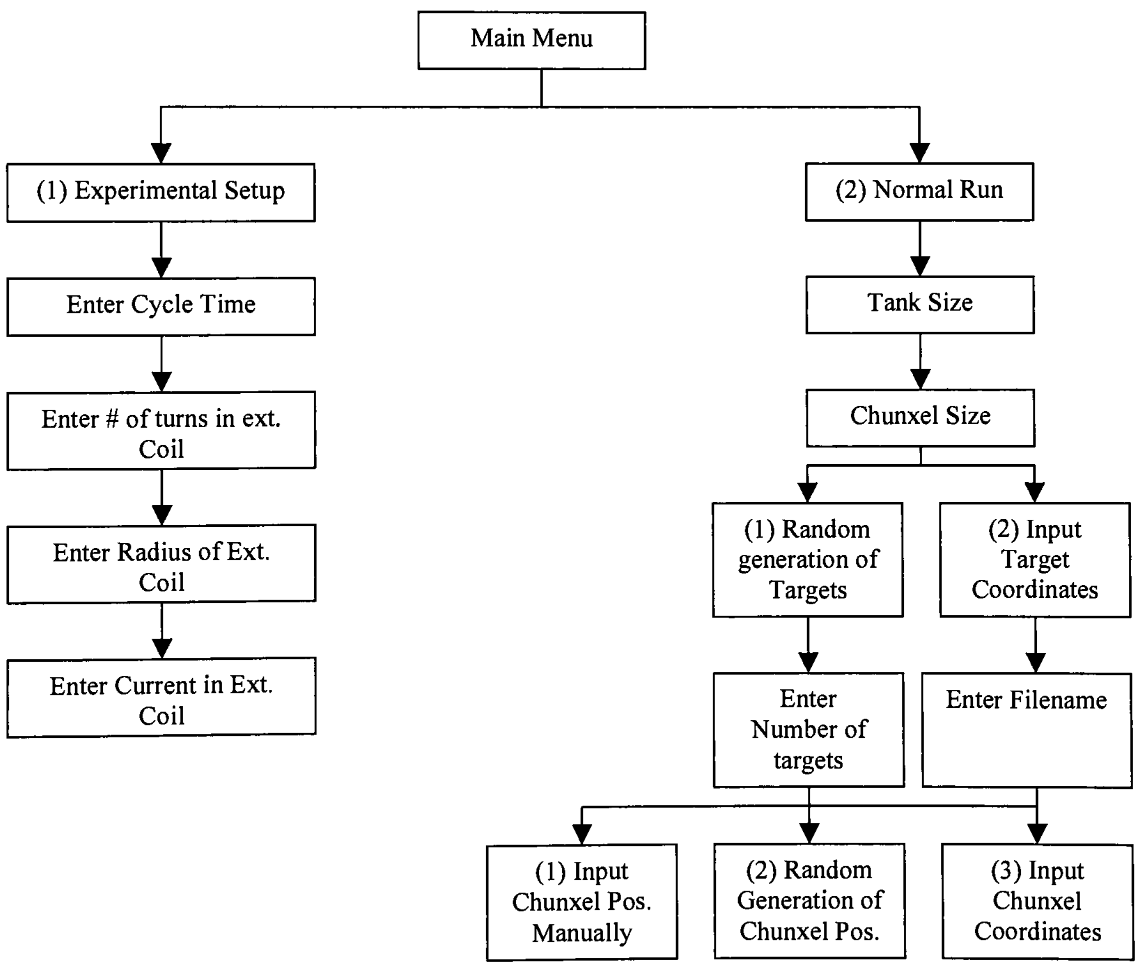

Figure 24: Block Diagram showing the Start-up Options for 3D Simulation Tool

6.4. Phase 4: Verification of 3-D Simulation Tool

A Computer model is a numerical model converted to computer code so that the input and parameter values are entered into a computer and the program determines the associated output values. Simulation is the process of designing a computer model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and/or evaluating various strategies for the operation of the system. A better definition in the context of robots is be given by the following statement "Simulation is a graphical computer program that represents the robot and it's environment, which emulates the robot's behavior during a simulated run of the robot. This is used to determine a robot's behavior in certain situations, before actually commanding the robot to perform such tasks. Simulation items to consider are: the 3-D modeling of the environment, kinematics emulation, path-planning emulation, and simulation of sensors"[3]

The main aim of this thesis was to model the chunxel device for the purpose of assessing its behavior under selected conditions and evaluating the control strategies used for the device. In order to have the required confidence in the developed simulation model it was imperative to have the model verified and validated. Verification and validation are commonly used interchangeably in everyday language. But when it comes to simulation or a computer model they have two distinct meanings, even though a very thin line divides both of them.

Verification is the determination that the numerical model or computer model is a faithful representation of the mathematical model. Verification, which denotes establishment of truth, is possible only for the mathematical steps. In the case of a computer program, verification deals with checking the programming logic more than anything and to verify that the program is doing what it is supposed to do, or what the user wants it to do.

[3] (www.unt.edu/robotics/glossaryS-V.htm).

Validation goes a step further and determines the extent to which a model is well founded and fulfills the purpose for which it was constructed. Validation denotes the establishment of legitimacy or in other words how well the computer model is a faithful representation of the actual system or device. Validation requires verification and successful evaluation.

6.4.1. Program Setup and Response Variables

In this phase both verification and validation tests were performed so that experimentations could be performed using this simulation tool so as to get the optimal values for the various hardware parameters of the chunxel device. This experimentation was carried out in phase 6 of this research. The tests carried out for verifying and validating the model were not carried out separately and also the description given in this chapter deals with verifying and validating the model simultaneously.

The initial 3D Simulation program explained in the phase 3 was tweaked so as to get the various data values from the program. These values were stored by the program in "text" files with extension .txt, which could then be converted in Microsoft Excel files and analyzed by generating graphs and charts. The data values for each direction were written or stored in different files so as to sort the data depending upon which direction the chunxel moved in. So for example when the chunxel moves in the West direction the information is stored in "westdata.txt" file and similarly for the other directions. The data collected was for:

- The simulation time (ST).
- The co-ordinate values (x, y and z) at the ST.
- The propulsion, drag and total force at that co-ordinate value at ST.
- Similarly for the given ST the acceleration, velocity of the chunxel and the Time ON remaining of the internal coil.
- Also the coasting velocity was included. This coasting velocity was the velocity in the direction in which the chunxel moved in the direction of the last energized coil.

Along with this the program gave the standard deviation of the chunxel after it reached the target and the time it took for the chunxel to reach its target, which is termed as the simulation end time. The standard deviation represents the amount of oscillation the chunxel experienced about the mean target position, after the chunxel was said to be "locked" to the corresponding target. This information was important in order to analyze the effect of the proportional feedback motion incorporated in the chunxel control algorithm.

6.4.2. Experimental Set-up

For validation purposes the data obtained from the simulation run was compared to the force values from an initial experiment done to map the force values inside the tank. The parameter values used for that experiment had to be the same as the configuration used in the simulation run. Thus the experimental setup for the simulation validation run were as follows:

Tank size = 300 mm

Chunxel size = 25 mm

Cycle time = 1000 msecs = 1 sec.

Number of turns external coil (N_1) = 1000

Number of turns internal coil (N_2) = 100

Radius of external coil (R_1) = 76 mm

Radius of internal coil (R_2) =10 mm

Current in the external coil (I_1) = 2.0 amps =2000 milli amps.

Current in the internal coil (I_2) = 63 milli amps = 0.063 amps

The initial chunxel position was 0.25m, 0.15m, 0.15m in x, y, and z-axis respectively with the target position being 0.01m, 0.15m, 0.15m again in x, y, and z-axis. Thus the chunxel had to move only in the west direction and the data would be collected for all the variables under consideration from x=0.25 to x=0.01 on the major axis of the west coil and stored in "westdata.txt" file. Except for the Coasting velocity which was obtained from the "northdata.txt" file since the energizing was in the order West-North-Back-East-South-Forward and the coasting velocity in west direction would be obtained in the direction of the coil which is energized after west direction coil i.e. north.

6.4.3. Force Test

The first test was carried out to compare the force values and the force curves of the simulation run and the actual data collected in one of the experiments conducted in order to map the force values at different positions inside the tank. The acceleration and velocity curves were also studied from the data collected in this test to see if the values obtained are as expected. The simulation time was verified to see if the program was calculating the new chunxel positions after each time interval dt. The Time On curve of the internal coil was generated and latter in the chapter is used to compare it with the Time ON curve for the test, which incorporated proportional feedback motion. The effects of proportional feedback motion and coasting were neglected in this test and were analyzed separately. The "westdata" excel file showing the data is attached in the Appendix C. The graphs generated from this data for different response variables stated above are analyzed below:

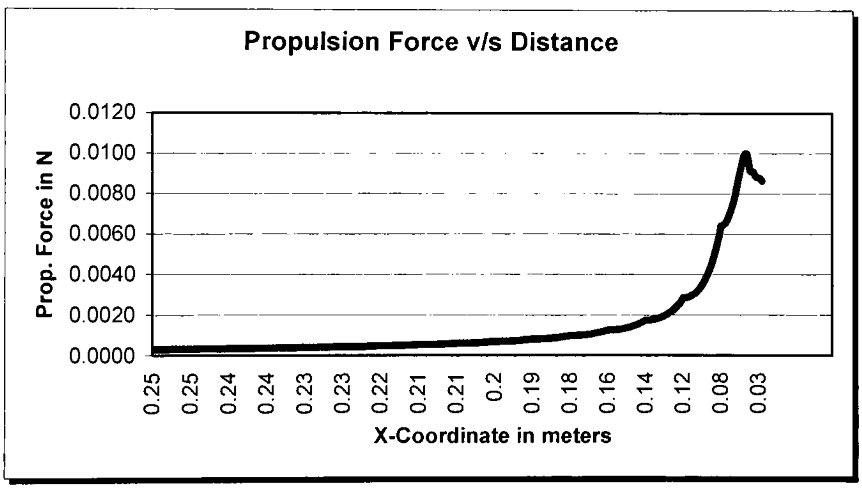

Figure 25: Propulsion Force v/s Distance from the Coil

Figure 25 shows the magnetic propulsion force with respect to the distance of the internal coil from the external coil. The increment in the force is very slow from .25 to .15 meters from the energized coil and then a sudden increase from .15 meters till it reaches the peak value of .01N roughly at a distance of .03 meters from the coil. After this the force rapidly decreases and tends to zero. This is because of the fact that no magnetic lines of force pass from the center of the external coil at a distance very close to the coil and hence there is no magnetic field to attract the internal coil. This curve is in accordance with the curve obtained from mapping the force values inside the tank in the initial actual experiment conducted on the chunxel device. In accordance with the force increase the velocity curve obtained is also similar and is shown in Figure 26 below.

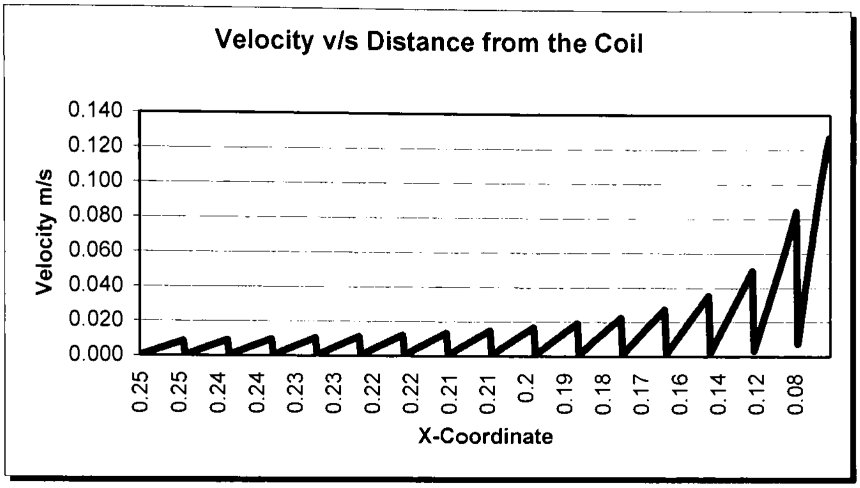

Figure 26: Velocity v/s Distance from the coil

The velocity increases in a linear fashion. The maximum point being .13 m/s at a distance of roughly .04 meters from the coil. During each cycle the velocity starts from 0 m/s thus in the graph there is a sudden decrease in the velocity from its local maximum to zero. This is not the actual change in velocity during the motion of the chunxel but actually marks the beginning of the next coil energizing cycle. The displacement of the chunxel is shown in Figure 27. Again here it is noted that the curve falls downs steeply after 72 seconds of the simulation time, which is when the force experienced by the chunxel and velocity of the chunxel suddenly increase.

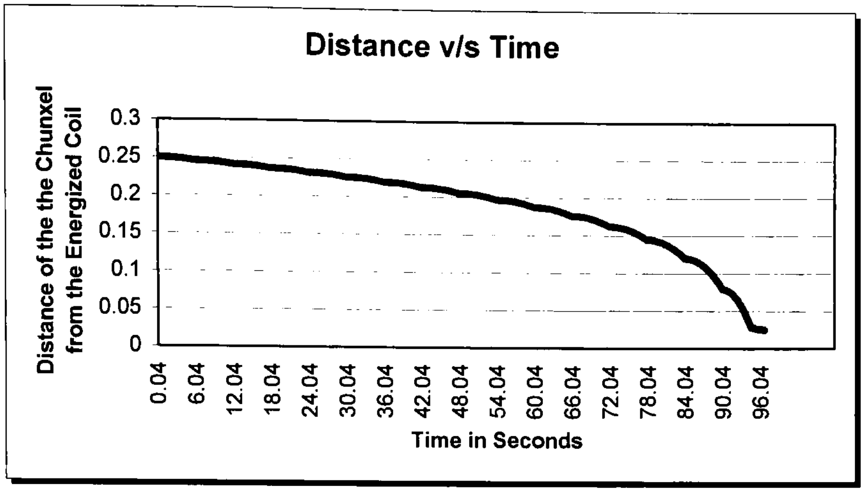

Figure 27: Distance from the Coil v/s Time

At 72 seconds it can be seen from the data file that the x-coordinate value or the distance between the chunxel and the energized coil is .16 meters.

From the data file it is also verified that the position of the chunxel is updated after every .04 seconds. With a cycle time of 1 second in the experiment, and the frame rate set to 25 frames per second, the computation for the new position has to be done every .04 seconds, which is the rate at which the data is added to the file implying that the programming logic for position update and screen refresh is working the way it was designed. The only thing to be noted here is that since the data file shown here is only for the west direction and the data is segregated as per the direction the chunxel is moving, the simulation time shown or collected in the 'westdata' file is only when the chunxel is moving in the west direction or when the west coil is energized. Thus the data shown jumps of 5 seconds after each time the west coil is energized. This also proves the point that the program is following the coil energizing sequence with a cycle time of 1 second.

6.4.4. Coasting Test

The force test was carried out without the effects of coasting being considered. In the coasting test the effects of coasting were considered and it can be seen from the data and the graph that coasting plays a major role in the chunxel behavior. The simulation end time without coasting was near to 96 seconds while with coasting the chunxel reaches its target in less than 40 seconds. Figure 28 shown the relationship of the x-coordinate of the chunxel against time.

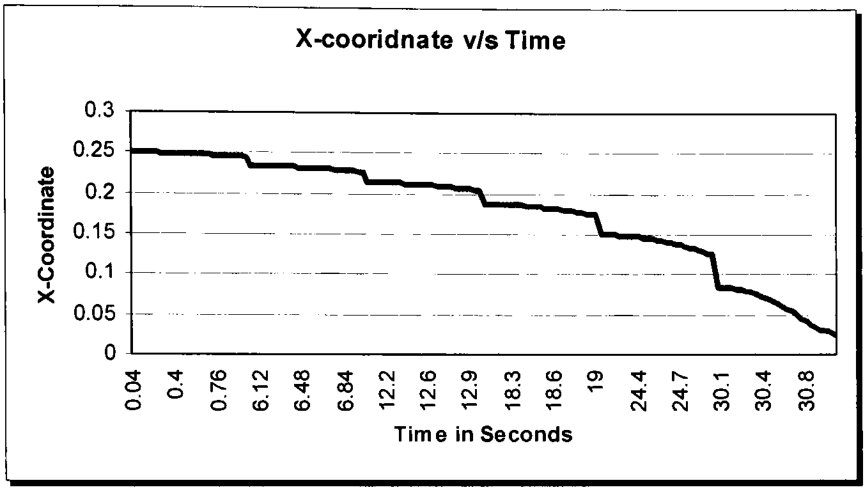

Figure 28: Distance from the Coil v/s Time (with influence of Coasting)

The sudden change in the x-coordinate is the result of coasting. Although the curve does not show the behavior of the chunxel during coasting but it just shows the change is x-coordinate of the chunxel caused because of the coasting motion. This is because the time step available in the data file are not continuous but are available only when the chunxel is moving in the direction considered, which is west in the case of this experiment.

6.4.5. Cos-Factor Test

In order to verify the proper calculation of the cos-factor in the force equation an experiment was conducted. This experiment was visual observation of the behavior of the chunxels. No test data was collected or tested since the actual values for comparison were not available. The introduction of the cos-factor in the first order force equation does one of the thing, the force experienced by the chunxel goes on decreasing as the chunxel moves away from the major axis of the external coil. Thus as the angle increases between the major axis of the external coil and the axis of the internal coil, the force values obtained are smaller than those of the chunxel which is on the major axis. The initial setup of the chunxels and the target locations is shown in Figure 36 (a) in Appendix D. As per this setup the chunxel on the major axis should reach its target first, then the four chunxels near the walls of the tank and the last ones to reach should be the chunxel at the extreme corners of the tanks. This is because as the propulsion force on the chunxel reduces the acceleration and thus the velocity is also reduced. This exact behavior was seen in the experiment, which increased the confidence level in this simulation program. The screenshots of the experiments are seen in the Appendix D.

6.4.6. Proportional Test

Two experiments were carried out for this test. With the same configuration, the only difference being in one experiment the proportional feedback motion was turned OFF and in the other it was turned ON. Both the experiments were carried out in the 'Experimental Mode' of the simulation tool. This was done so as to get the values of the standard deviation and simulation end time, which are unavailable in the 'Normal Run' mode. The data in this case is collected after the chunxel reaches the target for the movement of the chunxel about the mean position of the target it has arrived on. The first thing to notice is the graph of Time ON for both the experiments. The Time ON in the test without proportional feedback motion always starts at 100% of the cycle time irrespective of the distance between the chunxel and the target, while when the proportional feedback motion is left ON the maximum value of the Time ON period varies from 100% to 2% depending upon the distance between the chunxel and the target. The graphs are shown in the Figure. This verifies the fact that the programming logic is working fine, which is double-checked by comparing the standard deviation values.

Standard deviation tells how spread out numbers are from the average, calculated by taking the square root of the arithmetic average of the squares of the deviations from the mean in a frequency distribution. Once the chunxel reaches the target, the chunxel starts to oscillate about this target coordinate. At the instance, the chunxel is locked to the specific target; the program starts storing the chunxel co-ordinates after each cycle. In this case since the experiments were carried out for the chunxel moving in west direction, all the x-coordinates of the chunxel were stored in an array in the program. Taking these numbers a standard deviation or spread of these numbers was calculated taking the mean of the data values as the x-coordinate of the target. Thus the standard deviation represented the amount of oscillation the chunxel performed about the target location. Higher the value of standard deviation, more was the oscillation or hunting of the target by the chunxel.

The values obtained for standard deviation clearly showed that the proportional feedback motion greatly reduces std. deviation, which implies that the amount of oscillation or hunting is reduced and the control strategy is working as it was proposed at the start of this research. Since working in the experimental mode, as the tank size is fixed to 500 mm, the experimental parameters were changed so as to compensate for the size of the tank. This configuration along with the results obtained is attached in Appendix E. the initial chunxel position and the target coordinates were set as (.30, .25, .25) and (.10, .25, .25) respectively. All the x-coordinates were on the major axis of the west coil, so as to maximize the propulsion force.

As explained in Phase 3, the Time ON period of the chunxel is the main component of the proportional feedback motion of the chunxel. In the experiments run, one with proportional feedback motion (PFM) Off and the other with PFM ON the following Time ON graphs were obtained. The first graph (Figure 29) shows a constant Time ON period of 100% at the start of the cycle. This graph was generated by the experiment where PFM was OFF. In the second graph (Figure 30) the Time ON period decreases as the chunxel comes closer to the target, but is constant when it is away from the target by more than .1 meters. This verifies that the PFM logic in the program is working as designed.

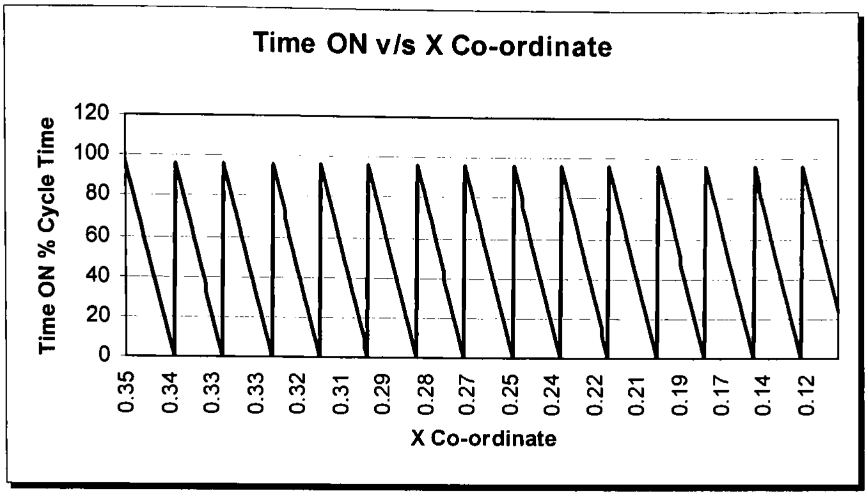

Figure 29: Time ON for the Internal Coil without Proportional Feedback Motion

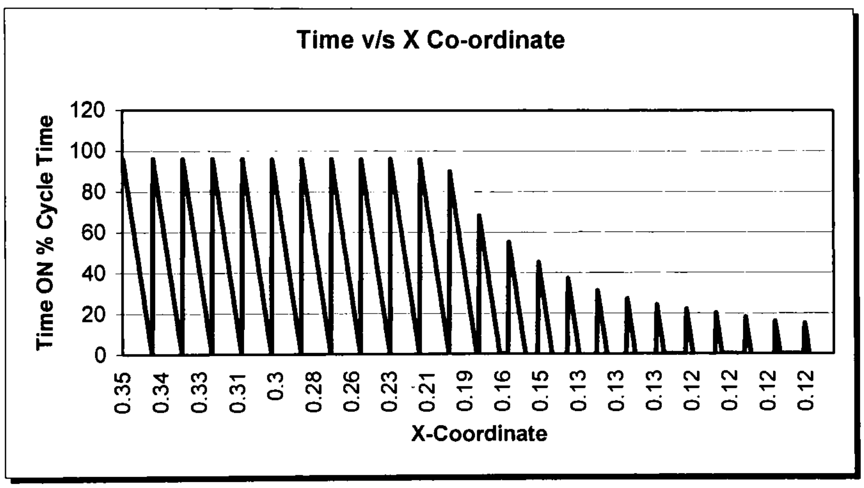

Figure 30: Time ON for Internal Coil with Proportional Feedback Motion

What is interesting to see here the oscillations that the chunxel undergoes with Proportional feedback motion ON and OFF. Figure 31 and 32 show these oscillations. Figure 31 shows the oscillations of the chunxel with PFM OFF and Figure 32 shows them with PFM ON. In this experiment the mean target position was .15 in the x axis. It is seen from the graphs that with PFM OFF the chunxel is constantly moving between the X co-ordinate values of 0.160 and 0.120, a range of .04 meters. While with PFM ON this range is reduced to .002 meters, the chunxel oscillating between the co-ordinates 0.150 to 0.148. Thus, there is a marked reduction in the oscillations using proportional feedback motion

This is further verified by the standard deviation with PFM OFF was obtained to be .009 while with PFM ON was 1.65E-5, which is much lower that the first value. Thus it can be inferred that the proportional feedback motion effectively reduces the hunting effect.

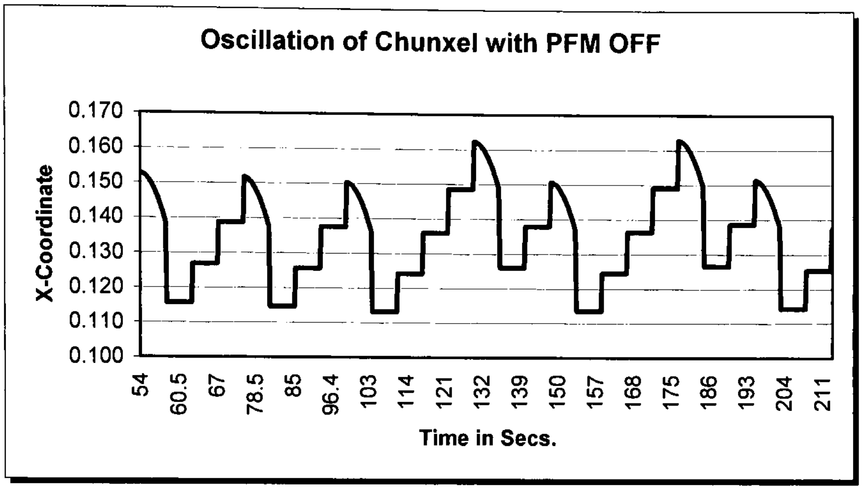

Figure 31: Oscillations of the Chunxel with Proportional Feedback Motion OFF

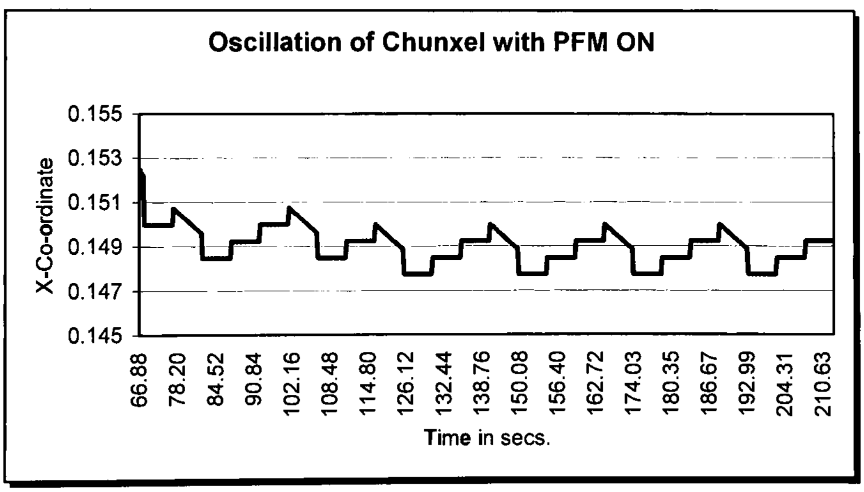

Figure 32: Oscillations of the Chunxel with Proportional Feedback Motion ON

6.5. Phase 5: Experimentation and Optimization using the 3-D Simulation Tool

A computer-simulated model of the real system is developed so as to perform various experiments that can help to improve the efficiency of the model or in other words improve the overall performance of the system. Also in many cases the simulated model is a good way to understand the system or the mathematical model in absence of the actual system. Along with understanding the behavior of the chunxels and observing the change in their behavior after implementing the control algorithm, this simulation program was developed to build a bigger and better chunxel device for the next generation of this device. In order to achieve this the hardware parameters of the chunxel device were to be properly selected so as to give the desired chunxel motion. The major considerations for a improved chunxel device was the completion of the 3-D geometry in a reasonable time and reduce the hunting to acceptable limits. Phase 6 of this research was to fix these values so as to make a more efficient and practical chunxel device.

To achieve this goal, design of experiments was used as a tool to analyze and get an optimal solution for the values of the desired hardware parameters. Talking in terms of Design of Experiments, the various factors affecting the motion of the chunxel inside the tank were to be adjusted so as to get an optimal solution for the time it takes by the chunxel to reach a target and after reaching the target to have minimal hunting.

As explained in the statement of problem, the factors affecting the chunxel motion are the number of turns, radius, and the current of the internal and external coil and the cycle time of energizing coil. The response variables in this case are the time taken by the chunxel to reach the target or the simulation end time and standard deviation as defined in phase 4. The design limitation of the chunxel eliminates the possibility of taking the number of turns, radius and the current of the internal coil as factors that can be varied. Thus keeping these as constant factors, the number of turns, radius, current of the external coil and cycle time are considered as variable factors, whose values have to optimized in order to get acceptable values for the response variables.

6.5.1. Design of Experiments: Experiment 1

As mentioned in the previous section four factors were selected for conducting the design of experiments. As the behavior of the device was not completely known, selection of the levels for this experiment were taken as three for all the four factors. The idea was to comprehend how the factors affected the chunxel motion and analyze the effects at these three different levels and then refine the search for the optimal solution with two levels for the second experiment. The time taken for a single run was very small and thus two experiments with a full factorial design was perfectly acceptable and a practical approach towards the optimization problem. Also a full factorial design enabled not only to statistically understand the motion of chunxel but also deduce some intuitional inferences from the results obtained. All this was because of the absence of the actual device to experiment on and very less prior knowledge of the whole system. Given below is the first experiment setup:

Tank size = 500 mm

Chunxel size = 25 mm

Number of turns of internal coil = 100

Radius of the internal coil = 10 mm

Current in the internal coil = 63 milli amps

The design of experiment was a 4 factor 3 level full factorial design with 81 runs. The different factors and their levels are as shown in the Table 3.

Table 3: Factors and Levels for Experiment 1

No.	Factor	Level 1	Level 2	Level 3
1	Cycle time	1000 msec	2000 msec	3000 msec
2	No. of turns of ext. coil	1000	3000	5000
3	Radius of ext. coil	250 mm	300 mm	350 mm
4	Current in the ext. coil	2000 mAmps	4000 mAmps	6000 mAmps

The lower limits of the design were the ones employed in the prototype run, the higher levels were chosen by some preliminary tests conducted using the simulation tool that showed some encouraging results as far as the response variables were concerned. The experiment results are attached in the Appendix F.

The response variables were:

1. Simulation end time in seconds, and
2. Standard deviation obtained

6.5.2. Analysis I

The analysis of the 81-run experiment was done using Minitab statistical software. The Minitab output is attached in appendix F.

The analysis of variance for response time as well as standard deviation or oscillations showed a p-value greater than 0.10, for radius of external coil. This showed that it was not a significant factor. This fact was also verified from the main effects plot shown in Figure 33 and Figure 34.

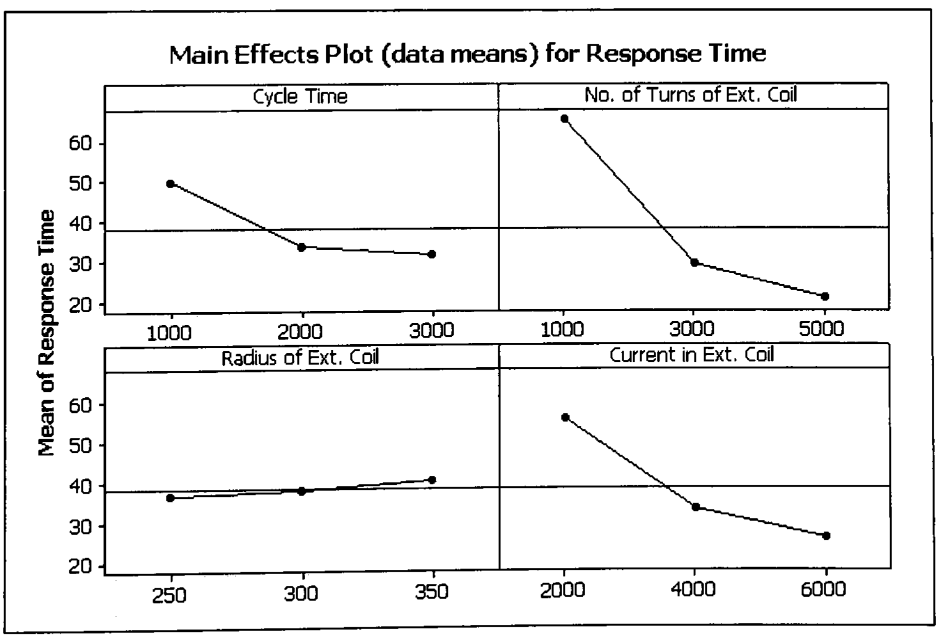

Figure 33: Main Effects Plot for Response Time

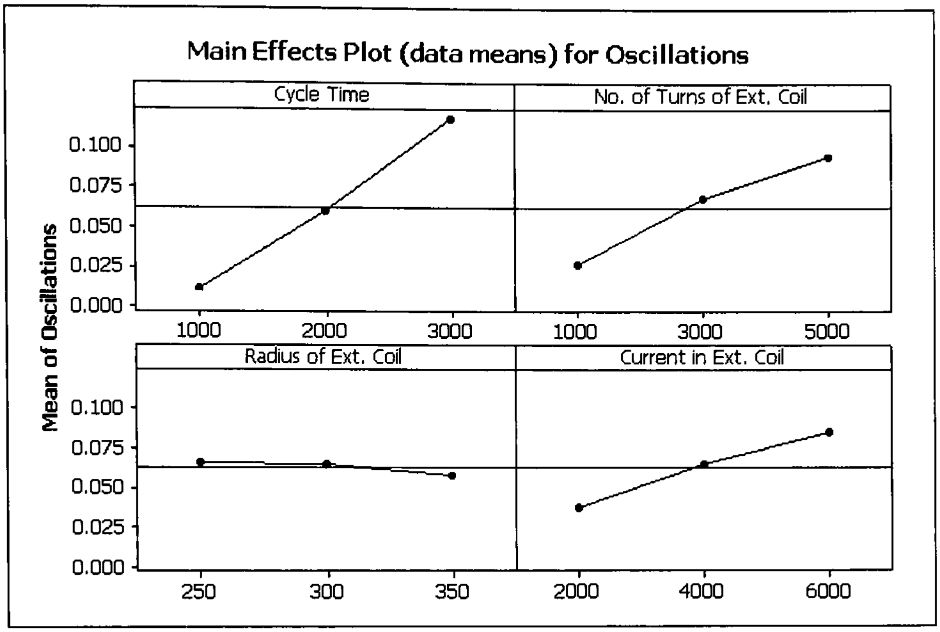

Figure 34: Main Effects Plot for Std. Deviation (Oscillations)

All other factors viz. cycle time, number of turns of external coil, and current in the external coil are significant factors. An increase in any one of the factors led to a decrease in the response variable time and increase in the standard deviation.

From the main effects plot for time it was observed that the change in response variable time was appreciable from cycle time 1000 to 2000 msec. Again the rate of change of response variable time was more from 1000 to 2000 number of turns that from 2000 to 3000. There is a steep reduction in time when the current changes from 2000 mAmps to 4000 mAmps.

Study of the main effects plot for standard deviation showed a linear increase in standard deviation for each level of each of the factors. Since the aim is to reduce the standard deviation, again the values from 1000 to 2000 msec for the cycle time, 1000 to 2000 number of turns and 2000 to 4000 mAmps were found to be practical limits for the further study to optimize the chunxel device.

6.5.3. Design of Experiments: Experiment 2

The first experiment showed that the radius of external coil was an insignificant factor. Also it helped in reducing the range of the other factors. With these new ranges it was possible to fine-tune the parameters of the chunxel device so as to get an optimal solution. The desired solution was to reduce the time keeping the standard deviation at its minimum. For this a Box-Behnken design was selected. A Box-Behnken design is a response surface design. The other response surface design is the Central Composite Design (CCD). The former was chosen to carry out the experimentation because the CCD gives a 5-level design with one center point and 2 points at the extreme side of the levels selected. Since there was no need for considering the factors at the extreme points, a Box-Behnken design was selected. A three factor, 2 level design with one center point was created using Minitab. The factors and their levels are as shown in the Table 4 below:

Table 4: Factors and Levels for Experiment 2

No.	Factor	Level 1	Level 2	Center-point
1	Cycle Time	1000 msec	2000 msec	1500 msec
2	No. of turns of ext. coil	1000	3000	2000
3	Current in the ext. coil	2000 mAmps	4000 mAmps	3000 mAmps

The experiment along with the results in shown in Appendix G.

6.5.4. Analysis II

The final goal of the experimentation was to find an optimal set of parameters that would reduce the time it takes for the chunxel to reach its target and at the same time reduce the hunting effect. This was achieved in the second experiment by running the response optimizer for the response surface design available in Minitab. In the response optimizer the software tries to find a global solution depending upon the goals set by the user. As per the visual and statistical results obtained in the previous experiment and preliminary runs, a standard deviation of 1% of the tank size was permissible. Also from the runs in the Box-

Behnken design it was observed that the chunxel could achieve its target in 25 seconds but with higher values in the standard deviation. Thus taking 25 seconds as the target value for time and .005 meters as the upper limit for the standard deviation, the response optimizer was set to calculate the best available configuration. The optimum values for the three factors are given in Table 5.

Table 5: Optimum Values of the Factors from Response Optimizer

Factor #	Factor	Optimum Value
1	Cycle time	1001.49 msec
2	No. of turns in external coil	3000
3	Current in the external coil	2768.72 mAmps

The response optimizer also gave the predicted values for the response variables as shown in Table 6.

Table 6: Predicted Values for Response Variables

Response Variable	Predicted Value
Time	38.8102 seconds
Standard deviation	.0050

Based on the optimum values for each factor, the simulation was run which gave the simulation end time as 36.07 seconds and standard deviation as .0044. This was in close agreement with the results obtained from the response optimizer, but a closer study of the runs showed that the 7th run yielded similar results with lesser number of turns and higher current. The configuration for the 7th run is given in Table 7. The values obtained for the response time and oscillations measured as standard deviation are 36.80 seconds and 0.00392 respectively.

Table 7: 7th Run Configuration

Factor #	Factor	Value
1	Cycle time	1000 msec
2	No. of turns in external coil	2000
3	Current in the external coil	4000 mAmps

This setup was preferable rather that the former because of the practical design considerations. A 3000-turn coil would be very bulky, than a 2000 turn coil. Also increasing the current is a better way to achieve efficiency as far as the space occupied by the device was concerned. Also since the cycle time was to be 1000 msec in either case, which is quite small time interval, heating of the coil is not considered to be a problem because of the high current passing through the coils.

Considering all these factors the final configuration was decided to be same as that in the 7^{th} run of the second experiment.

7. Conclusions & Future Research

7.1. Results & Conclusion

The scope of this thesis was to develop a control algorithm to form 3D structures based on swarm behavior and simultaneously design a simulation tool to test this algorithm. Furthermore, it was required to optimize the various physical parameters of the system in order to take the chunxel technology to the next stage of development. Keeping these objectives in mind, this research was carried out in various stages.

In the first stage, which was the building block of this research a swarm-based rule of reaching the nearest target was implemented in the 2D simulation program. In the next step it was successfully demonstrated that a group of chunxels could display synergistic behavior and complete a task, which would be impossible for a single chunxel to perform. The 2D simulation tool effectively showed how a non-working or "dead" chunxel could be lifted above the liquid medium inside the tank.

However the main objective was to build a simulation model that would represent the actual system. Thus using Java 3D as a tool, a 3-Dimensional chunxel simulation program was developed. The motion of the chunxel in this simulation was based on mathematical equations of magnetic forces of attraction and the chunxel obeyed all the physical laws of buoyancy, frictional drag and kinetic energy making the simulation as realistic as possible thus fairly representing the actual physical system. The 3D simulation program was verified by running a number of tests on it and the data from these tests was compared to the actual data available from the prototype run of the chunxel device. The 3D simulation tool included the nearest target swarm rule. Along with that a proportional feedback motion was incorporated. The results showed a considerable decrease in hunting of the target by the chunxel because of this proportional feedback motion.

The 3D simulation tool was helpful not only in understanding the behavior of the chunxel with the proposed control logic but also in understanding the effects of various physical parameters of the device on the motion of the chunxel. These effects were studied in detail by using design of experiments. Two experiments were conducted; the first one was a full factorial design with four factors and three levels, with 81 runs. A full factorial design was preferred in this case as the system behavior was not completely known and also the time taken for a single run was not significant. It was found that the cycle time, number of turns of the external coil and the current in the external coil were significant factors. The second experiment was a Box-Behnken used to optimize these three factors. Closer inspection of the different runs in this experiment and values obtained from the response optimizer led to the configuration shown in Table 8.

Table 8: Optimum Configuration

Factor #	Factor	Optimum Value
1	Cycle time	1000 msec
2	No. of turns in external coil	2000
3	Current in the external coil	4000 mAmps

This configuration will be helpful in making the next chunxel device prototype with a tank size of 500 mm using the current generation chunxel.

7.2. Future Research & Recommendations

This research has successfully fulfilled the objectives of developing a both 2D and 3D simulation tools. Basic control strategies were successfully developed and tested. This thesis has given a substantial framework and a foundation for developing and testing much more intricate control algorithms and synergistic strategies. Using the 2D simulation tool it has been shown that the chunxels can effectively perform synergistic tasks. Taking this as the first step, the same logic can be applied to the 3D simulation tool. Demonstrating synergistic behavior in the 3D simulation tool would be the next logical step. Simultaneously, exploration of additional sets of swarm rules would help in arriving at an optimal control strategy. Complimentary to this would be a hybrid approach of having a set of swarm rules for individual chunxels and along with that allowing the chunxels to have local inter-chunxel communication (Physical and Technological limitations permitting). Experimenting with such a strategy using the 3D simulation tool would be an interesting research.

Based on the current knowledge of the chunxel device and the work done in this thesis, it is possible to program the chunxels according to the proposed control strategy. This would help in making the next prototype, which would be a 500 mm tank and having the physical parameters as obtained from the optimization experiments. Along with the simulated testing, actual prototype tests would help not only in demonstrating the capabilities of the system but also help in fine tuning the simulation program which in turn can be used to develop much more intricate algorithms.

The simulation program developed in this thesis is the first of its kind in the ongoing research of the chunxel technology, and thus there are many areas where the simulation program can be improved upon. It has been observed that the simulation gets slower as the number of chunxels goes on increasing. This cannot be totally eliminated but with the current program only a few hundred chunxels can be simulated. Improving the software performance of the system would greatly help in simulating more chunxels and thus forming intricate 3D structures requiring more chunxels than the current system can support. It is highly recommended to use better collision detection algorithms as collision detection requires lot of computation and is the major roadblock in improving the performance of 3D simulations and programs. Other programming languages could also be considered for improving the performance of the 3D simulation tool.

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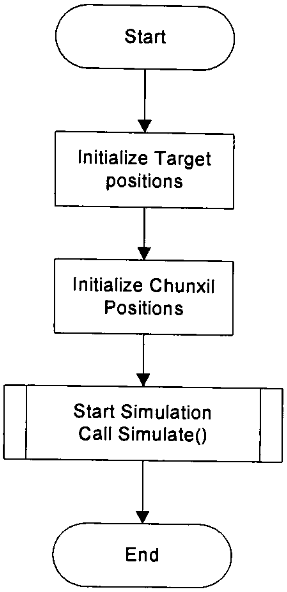
"A Tutorial Introduction to Swarm: Why Simulate?" See http://www.swarm.org/csss-tutorial/foil03.html

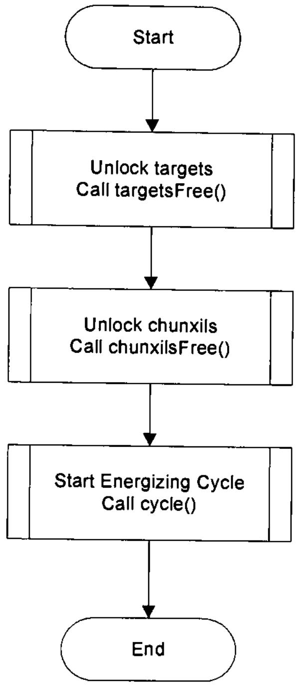
Appendices

Appendix A: 2D Simulation Flowchart

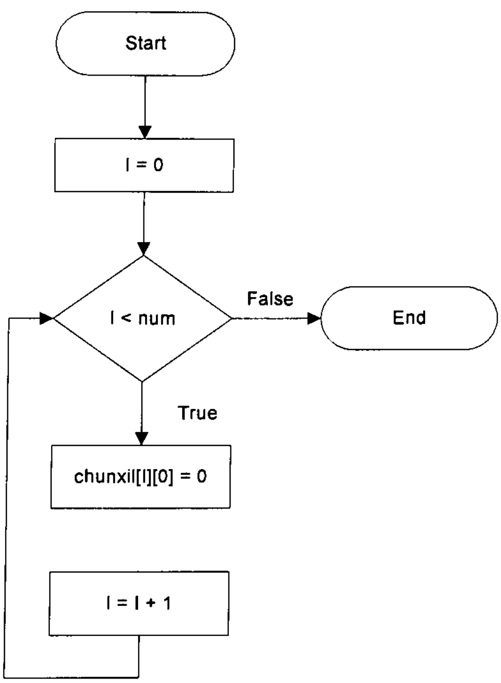
Main Program



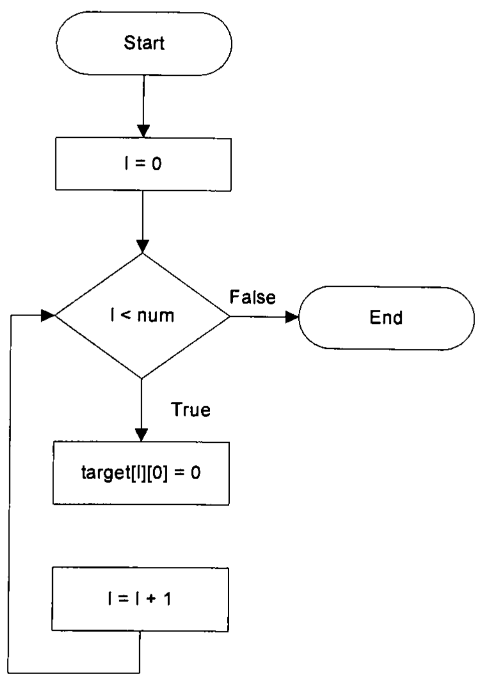
Method Simulate()



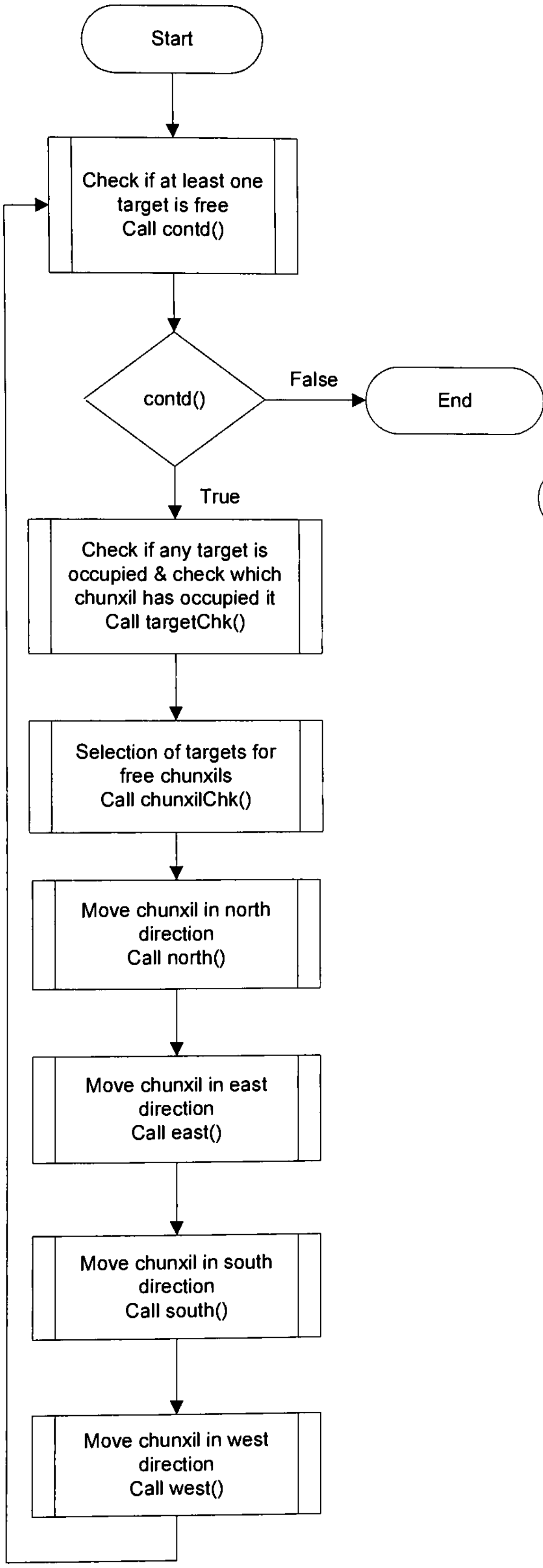
Method chunxilsFree()



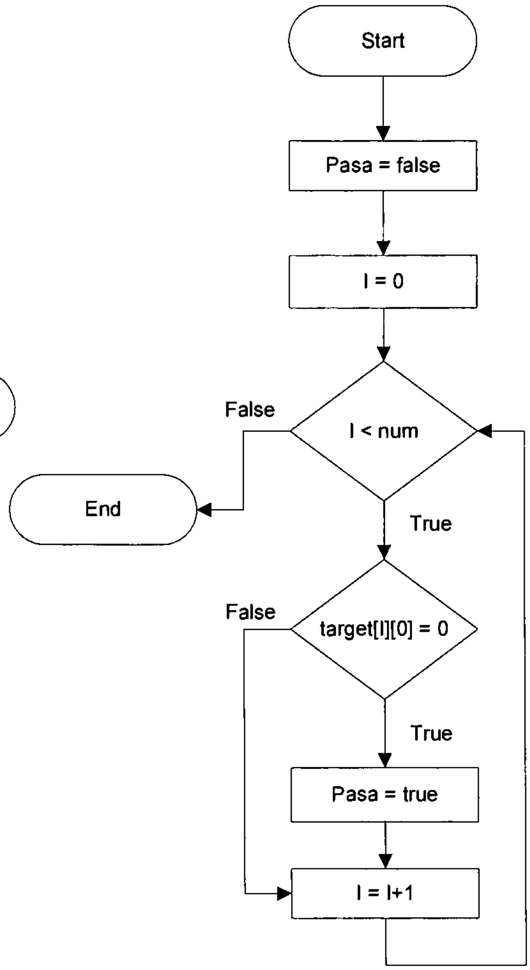
Method targetsFree()



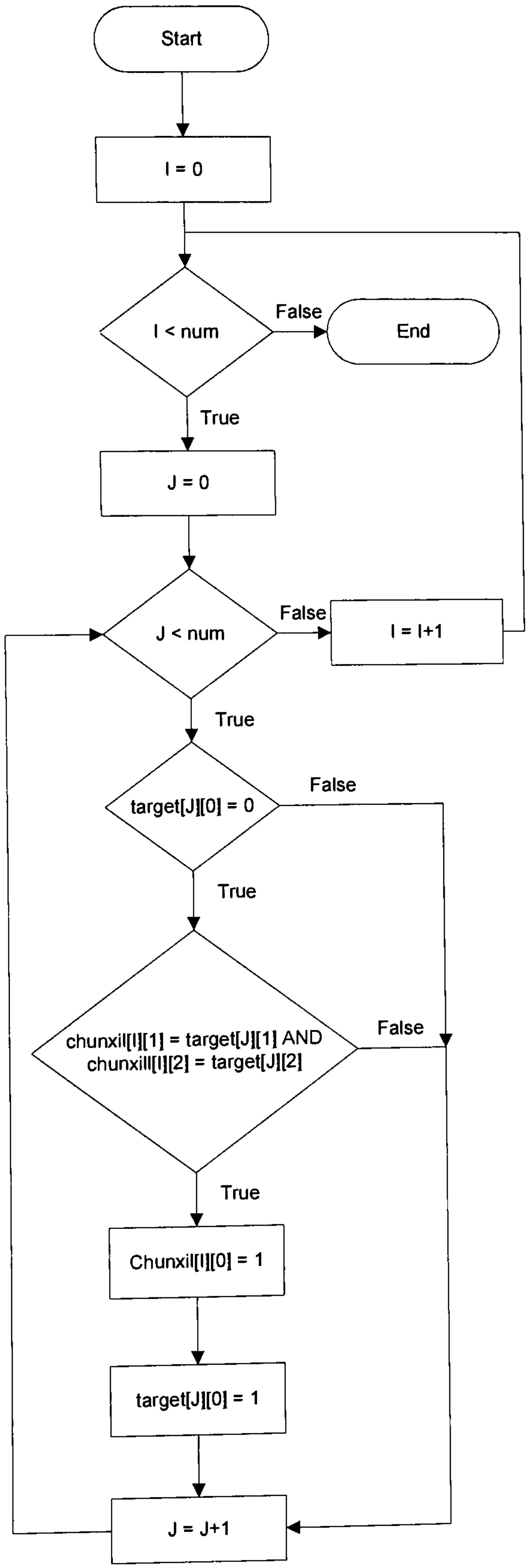
Method cycle()



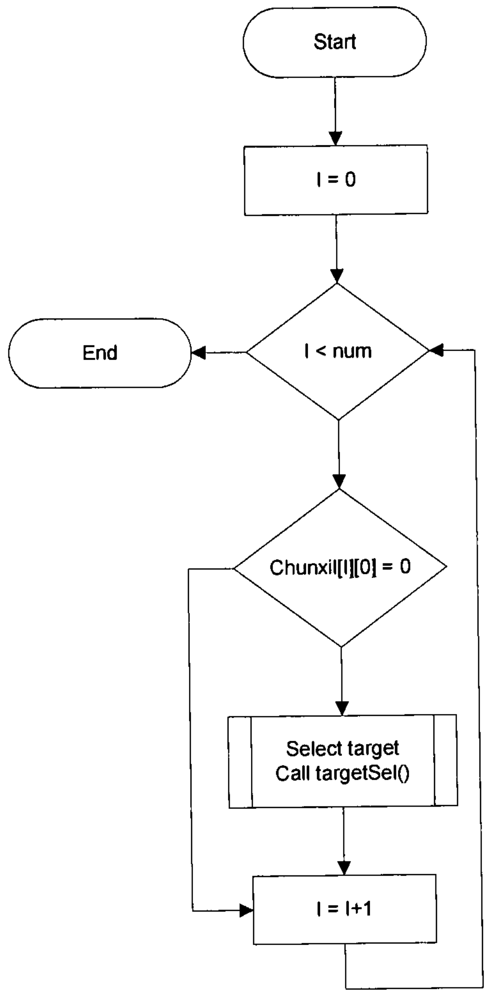
Method contd()



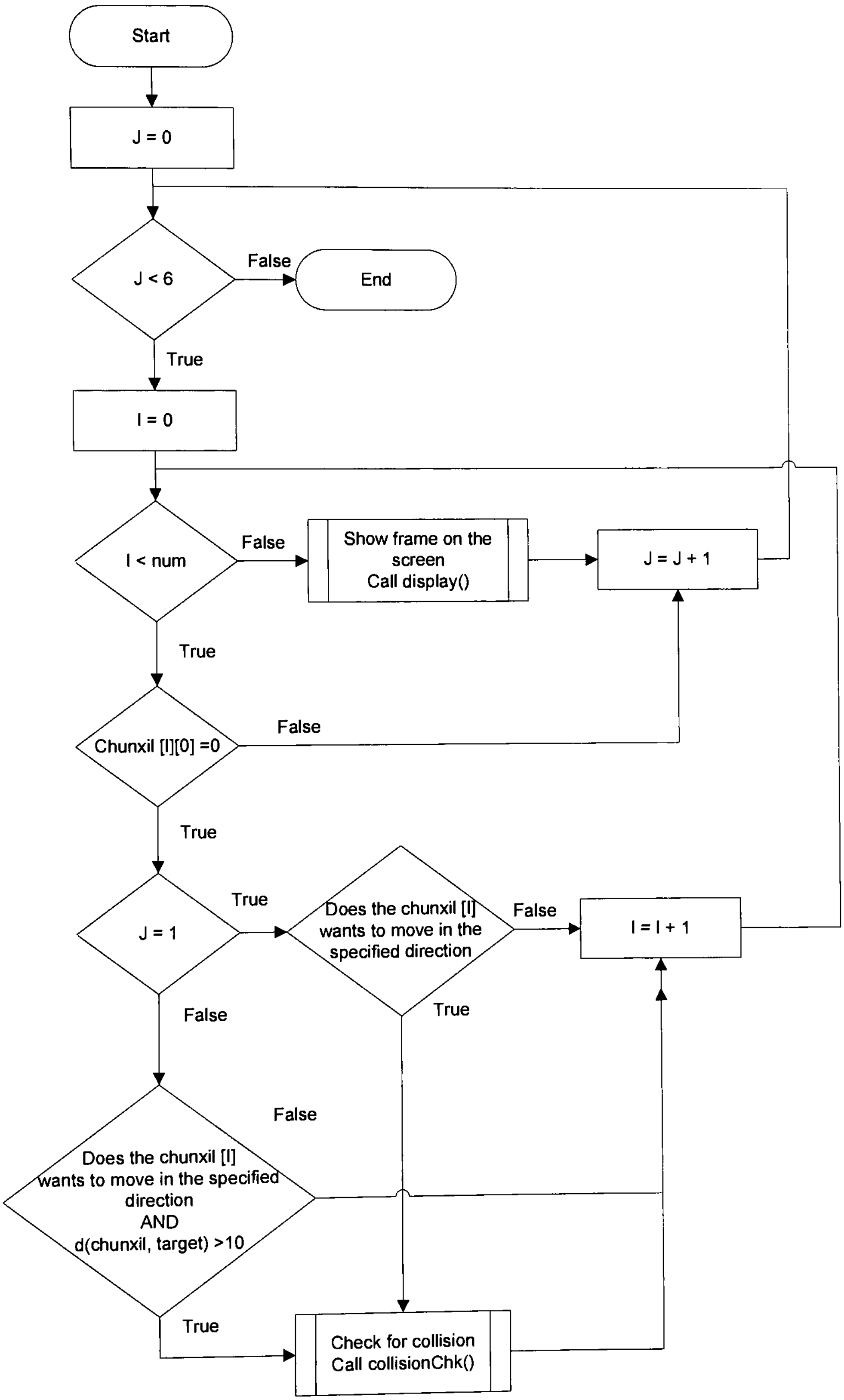
Method targetChk()



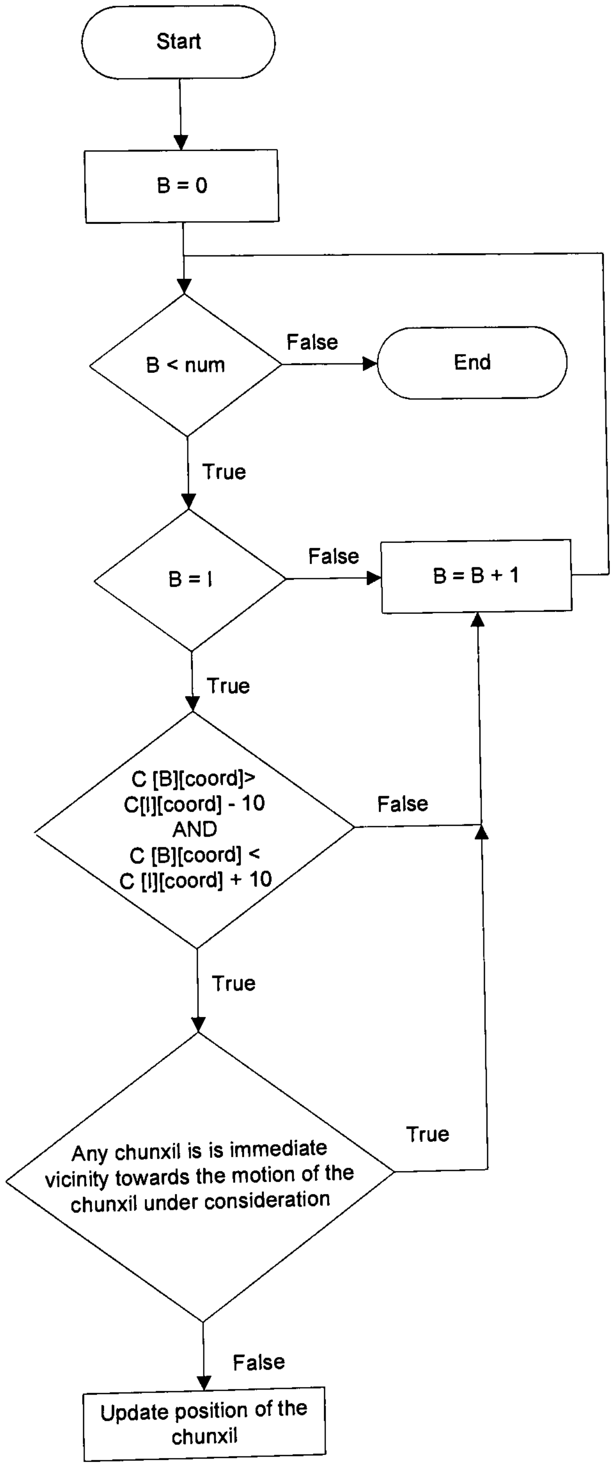
Method chunxilChk()



Directional Motion Methods
north(), south(), east(), west()



Method collisionChk(). Takes chunxil identifcation number I as an argument



Appendix B: Screenshot of 3D Simulation Tool

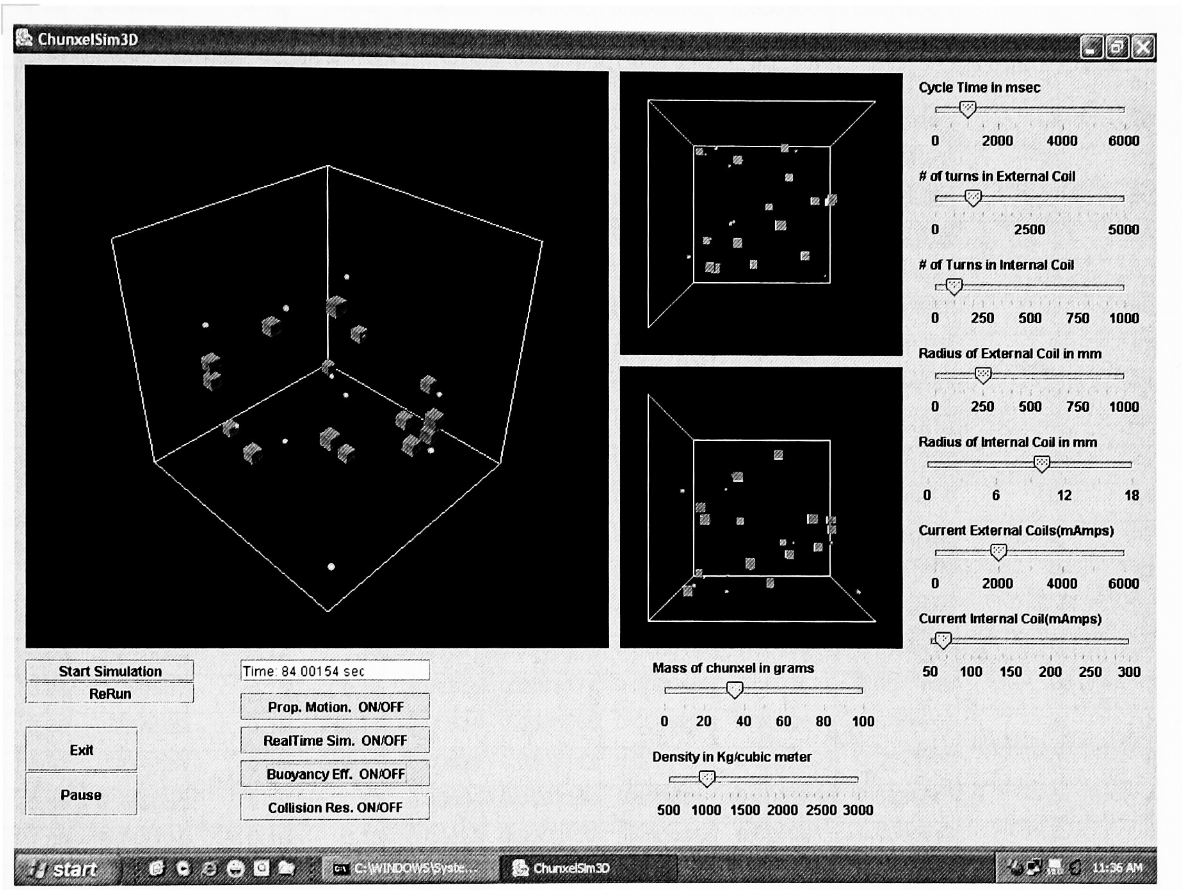


Figure 35: 3D Simulation Tool Screenshot

Appendix C: Date of Force Test

Table 9: Force Test data[4]

Time	X-coord	Y-coord	Z-coord	Eng.acc	PForce	DForce	TForce	Eng. vel	Coast vel	Time ON
0.04	0.249993	0.15	0.15	0.00859	0.0003005	0.0000000	0.0003005	0.0003434	0	96
0.08	0.249973	0.15	0.15	0.00858	0.0003005	0.0000000	0.0003005	0.0006868	0	92
0.12	0.249938	0.15	0.15	0.00858	0.0003006	0.0000002	0.0003004	0.0010301	0	88
0.16	0.24989	0.15	0.15	0.00858	0.0003007	0.0000004	0.0003003	0.0013734	0	84
0.20	0.249828	0.15	0.15	0.00858	0.0003010	0.0000008	0.0003002	0.0017164	0	80
0.24	0.249753	0.15	0.15	0.00857	0.0003012	0.0000012	0.0003000	0.0020593	0	76
0.28	0.249664	0.15	0.15	0.00857	0.0003015	0.0000017	0.0002998	0.0024020	0	72
0.32	0.249561	0.15	0.15	0.00856	0.0003019	0.0000023	0.0002996	0.0027444	0	68
0.36	0.249444	0.15	0.15	0.00855	0.0003024	0.0000030	0.0002993	0.0030865	0	64
0.40	0.249314	0.15	0.15	0.00854	0.0003029	0.0000038	0.0002990	0.0034283	0	60
0.44	0.24917	0.15	0.15	0.00853	0.0003034	0.0000047	0.0002987	0.0037697	0	56
0.48	0.249012	0.15	0.15	0.00852	0.0003040	0.0000057	0.0002983	0.0041106	0	52
0.52	0.248841	0.15	0.15	0.00851	0.0003047	0.0000068	0.0002979	0.0044511	0	48
0.56	0.248656	0.15	0.15	0.0085	0.0003054	0.0000079	0.0002975	0.0047912	0	44
0.60	0.248458	0.15	0.15	0.00849	0.0003062	0.0000092	0.0002971	0.0051307	0	40
0.64	0.248246	0.15	0.15	0.00847	0.0003071	0.0000105	0.0002966	0.0054696	0	36
0.68	0.24802	0.15	0.15	0.00846	0.0003080	0.0000120	0.0002961	0.0058080	0	32
0.72	0.247781	0.15	0.15	0.00844	0.0003090	0.0000135	0.0002955	0.0061457	0	28
0.76	0.247528	0.15	0.15	0.00843	0.0003101	0.0000151	0.0002950	0.0064828	0	24
0.80	0.247262	0.15	0.15	0.00841	0.0003112	0.0000168	0.0002944	0.0068192	0	20
0.84	0.246983	0.15	0.15	0.00839	0.0003124	0.0000186	0.0002938	0.0071550	0	16
0.88	0.24669	0.15	0.15	0.00838	0.0003136	0.0000205	0.0002931	0.0074900	0	12
0.92	0.246384	0.15	0.15	0.00836	0.0003149	0.0000224	0.0002925	0.0078242	0	8
0.96	0.246064	0.15	0.15	0.00834	0.0003163	0.0000245	0.0002918	0.0081577	0	4
1.00	0.245731	0.15	0.15	0.00832	0.0003177	0.0000266	0.0002911	0.0084904	0	0
6.04	0.245724	0.15	0.15	0.00912	0.0003193	0.0000000	0.0003193	0.0003649	0	96
6.08	0.245702	0.15	0.15	0.00912	0.0003193	0.0000001	0.0003192	0.0007297	0	92
6.12	0.245665	0.15	0.15	0.00912	0.0003194	0.0000002	0.0003192	0.0010945	0	88
6.16	0.245614	0.15	0.15	0.00912	0.0003196	0.0000005	0.0003191	0.0014591	0	84
6.20	0.245549	0.15	0.15	0.00911	0.0003198	0.0000009	0.0003189	0.0018236	0	80
6.24	0.245469	0.15	0.15	0.00911	0.0003201	0.0000013	0.0003188	0.0021879	0	76
6.28	0.245374	0.15	0.15	0.0091	0.0003205	0.0000019	0.0003185	0.0025519	0	72
6.32	0.245264	0.15	0.15	0.00909	0.0003209	0.0000026	0.0003183	0.0029157	0	68
6.36	0.24514	0.15	0.15	0.00909	0.0003214	0.0000034	0.0003180	0.0032791	0	64
6.40	0.245002	0.15	0.15	0.00908	0.0003220	0.0000043	0.0003177	0.0036422	0	60
6.44	0.244849	0.15	0.15	0.00907	0.0003226	0.0000053	0.0003173	0.0040048	0	56
6.48	0.244682	0.15	0.15	0.00905	0.0003233	0.0000064	0.0003169	0.0043669	0	52

[4] westdata.txt file converted to Excel Format

6.52	0.2445	0.15	0.15	0.00904	0.0003241	0.0000076	0.0003165	0.0047286	0	48
6.56	0.244303	0.15	0.15	0.00903	0.0003249	0.0000089	0.0003160	0.0050897	0	44
6.60	0.244093	0.15	0.15	0.00901	0.0003258	0.0000104	0.0003155	0.0054503	0	40
6.64	0.243867	0.15	0.15	0.009	0.0003268	0.0000119	0.0003149	0.0058102	0	36
6.68	0.243628	0.15	0.15	0.00898	0.0003279	0.0000135	0.0003144	0.0061695	0	32
6.72	0.243374	0.15	0.15	0.00897	0.0003290	0.0000152	0.0003138	0.0065281	0	28
6.76	0.243106	0.15	0.15	0.00895	0.0003302	0.0000170	0.0003132	0.0068861	0	24
6.80	0.242823	0.15	0.15	0.00893	0.0003315	0.0000190	0.0003125	0.0072432	0	20
6.84	0.242526	0.15	0.15	0.00891	0.0003329	0.0000210	0.0003119	0.0075997	0	16
6.88	0.242215	0.15	0.15	0.00889	0.0003343	0.0000231	0.0003112	0.0079553	0	12
6.92	0.24189	0.15	0.15	0.00887	0.0003358	0.0000253	0.0003105	0.0083101	0	8
6.96	0.24155	0.15	0.15	0.00885	0.0003374	0.0000276	0.0003097	0.0086641	0	4
7.00	0.241197	0.15	0.15	0.00883	0.0003390	0.0000300	0.0003090	0.0090173	0	0
12.04	0.241189	0.15	0.15	0.00974	0.0003408	0.0000000	0.0003408	0.0003894	0	96
12.08	0.241165	0.15	0.15	0.00974	0.0003408	0.0000001	0.0003407	0.0007789	0	92
12.12	0.241126	0.15	0.15	0.00973	0.0003409	0.0000002	0.0003407	0.0011682	0	88
12.16	0.241072	0.15	0.15	0.00973	0.0003411	0.0000005	0.0003406	0.0015574	0	84
12.20	0.241002	0.15	0.15	0.00973	0.0003414	0.0000010	0.0003404	0.0019465	0	80
12.24	0.240916	0.15	0.15	0.00972	0.0003417	0.0000015	0.0003402	0.0023353	0	76
12.28	0.240815	0.15	0.15	0.00971	0.0003422	0.0000022	0.0003400	0.0027238	0	72
12.32	0.240698	0.15	0.15	0.00971	0.0003427	0.0000030	0.0003397	0.0031121	0	68
12.36	0.240566	0.15	0.15	0.0097	0.0003432	0.0000039	0.0003394	0.0034999	0	64
12.40	0.240418	0.15	0.15	0.00969	0.0003439	0.0000049	0.0003390	0.0038873	0	60
12.44	0.240255	0.15	0.15	0.00967	0.0003446	0.0000060	0.0003386	0.0042743	0	56
12.48	0.240076	0.15	0.15	0.00966	0.0003455	0.0000073	0.0003381	0.0046607	0	52
12.52	0.239882	0.15	0.15	0.00965	0.0003464	0.0000087	0.0003377	0.0050466	0	48
12.56	0.239673	0.15	0.15	0.00963	0.0003473	0.0000102	0.0003371	0.0054319	0	44
12.60	0.239448	0.15	0.15	0.00962	0.0003484	0.0000118	0.0003366	0.0058166	0	40
12.64	0.239207	0.15	0.15	0.0096	0.0003495	0.0000135	0.0003360	0.0062006	0	36
12.68	0.238952	0.15	0.15	0.00958	0.0003508	0.0000154	0.0003354	0.0065839	0	32
12.72	0.238681	0.15	0.15	0.00956	0.0003521	0.0000173	0.0003347	0.0069665	0	28
12.76	0.238394	0.15	0.15	0.00954	0.0003535	0.0000194	0.0003341	0.0073482	0	24
12.80	0.238093	0.15	0.15	0.00952	0.0003549	0.0000216	0.0003333	0.0077292	0	20
12.84	0.237776	0.15	0.15	0.0095	0.0003565	0.0000239	0.0003326	0.0081093	0	16
12.88	0.237444	0.15	0.15	0.00948	0.0003582	0.0000263	0.0003319	0.0084886	0	12
12.92	0.237097	0.15	0.15	0.00946	0.0003599	0.0000288	0.0003311	0.0088670	0	8
12.96	0.236735	0.15	0.15	0.00944	0.0003617	0.0000314	0.0003303	0.0092445	0	4
13.00	0.236357	0.15	0.15	0.00941	0.0003637	0.0000342	0.0003295	0.0096210	0	0
18.04	0.236349	0.15	0.15	0.01045	0.0003657	0.0000000	0.0003657	0.0004179	0	96
18.08	0.236324	0.15	0.15	0.01045	0.0003657	0.0000001	0.0003657	0.0008359	0	92
18.12	0.236282	0.15	0.15	0.01045	0.0003659	0.0000003	0.0003656	0.0012537	0	88
18.16	0.236224	0.15	0.15	0.01044	0.0003661	0.0000006	0.0003655	0.0016714	0	84
18.20	0.236149	0.15	0.15	0.01044	0.0003664	0.0000011	0.0003653	0.0020889	0	80
18.24	0.236057	0.15	0.15	0.01043	0.0003668	0.0000017	0.0003651	0.0025061	0	76
18.28	0.235948	0.15	0.15	0.01042	0.0003673	0.0000025	0.0003648	0.0029230	0	72

18.32	0.235823	0.15	0.15	0.01041	0.0003679	0.0000034	0.0003645	0.0033396	0	68
18.36	0.235681	0.15	0.15	0.0104	0.0003686	0.0000045	0.0003641	0.0037557	0	64
18.40	0.235522	0.15	0.15	0.01039	0.0003694	0.0000056	0.0003637	0.0041714	0	60
18.44	0.235347	0.15	0.15	0.01038	0.0003702	0.0000070	0.0003633	0.0045865	0	56
18.48	0.235155	0.15	0.15	0.01036	0.0003712	0.0000084	0.0003628	0.0050011	0	52
18.52	0.234947	0.15	0.15	0.01035	0.0003722	0.0000100	0.0003622	0.0054151	0	48
18.56	0.234722	0.15	0.15	0.01033	0.0003734	0.0000117	0.0003616	0.0058284	0	44
18.60	0.234481	0.15	0.15	0.01032	0.0003746	0.0000136	0.0003610	0.0062410	0	40
18.64	0.234223	0.15	0.15	0.0103	0.0003760	0.0000156	0.0003604	0.0066529	0	36
18.68	0.233949	0.15	0.15	0.01028	0.0003774	0.0000177	0.0003597	0.0070640	0	32
18.72	0.233658	0.15	0.15	0.01026	0.0003789	0.0000200	0.0003590	0.0074742	0	28
18.76	0.233351	0.15	0.15	0.01023	0.0003806	0.0000223	0.0003582	0.0078836	0	24
18.80	0.233027	0.15	0.15	0.01021	0.0003823	0.0000249	0.0003574	0.0082921	0	20
18.84	0.232687	0.15	0.15	0.01019	0.0003841	0.0000275	0.0003566	0.0086997	0	16
18.88	0.232331	0.15	0.15	0.01017	0.0003861	0.0000303	0.0003558	0.0091064	0	12
18.92	0.231959	0.15	0.15	0.01014	0.0003881	0.0000332	0.0003550	0.0095120	0	8
18.96	0.23157	0.15	0.15	0.01012	0.0003903	0.0000362	0.0003541	0.0099167	0	4
19.00	0.231166	0.15	0.15	0.01009	0.0003926	0.0000393	0.0003532	0.0103204	0	0
24.04	0.231157	0.15	0.15	0.01128	0.0003949	0.0000000	0.0003949	0.0004514	0	96
24.08	0.231129	0.15	0.15	0.01128	0.0003950	0.0000001	0.0003949	0.0009027	0	92
24.12	0.231084	0.15	0.15	0.01128	0.0003952	0.0000003	0.0003948	0.0013539	0	88
24.16	0.231021	0.15	0.15	0.01128	0.0003954	0.0000007	0.0003947	0.0018050	0	84
24.20	0.23094	0.15	0.15	0.01127	0.0003958	0.0000013	0.0003945	0.0022559	0	80
24.24	0.230841	0.15	0.15	0.01126	0.0003963	0.0000020	0.0003942	0.0027064	0	76
24.28	0.230723	0.15	0.15	0.01126	0.0003969	0.0000029	0.0003939	0.0031566	0	72
24.32	0.230588	0.15	0.15	0.01125	0.0003976	0.0000040	0.0003936	0.0036065	0	68
24.36	0.230435	0.15	0.15	0.01123	0.0003984	0.0000052	0.0003932	0.0040558	0	64
24.40	0.230264	0.15	0.15	0.01122	0.0003993	0.0000066	0.0003927	0.0045046	0	60
24.44	0.230075	0.15	0.15	0.01121	0.0004003	0.0000081	0.0003922	0.0049528	0	56
24.48	0.229867	0.15	0.15	0.01119	0.0004014	0.0000098	0.0003916	0.0054004	0	52
24.52	0.229643	0.15	0.15	0.01117	0.0004027	0.0000117	0.0003910	0.0058473	0	48
24.56	0.2294	0.15	0.15	0.01115	0.0004041	0.0000137	0.0003904	0.0062934	0	44
24.60	0.229139	0.15	0.15	0.01113	0.0004055	0.0000158	0.0003897	0.0067388	0	40
24.64	0.228861	0.15	0.15	0.01111	0.0004071	0.0000182	0.0003890	0.0071833	0	36
24.68	0.228564	0.15	0.15	0.01109	0.0004088	0.0000206	0.0003882	0.0076270	0	32
24.72	0.22825	0.15	0.15	0.01107	0.0004107	0.0000233	0.0003874	0.0080697	0	28
24.76	0.227919	0.15	0.15	0.01104	0.0004126	0.0000260	0.0003866	0.0085115	0	24
24.80	0.22757	0.15	0.15	0.01102	0.0004147	0.0000290	0.0003857	0.0089523	0	20
24.84	0.227203	0.15	0.15	0.01099	0.0004169	0.0000321	0.0003848	0.0093921	0	16
24.88	0.226818	0.15	0.15	0.01097	0.0004192	0.0000353	0.0003839	0.0098308	0	12
24.92	0.226416	0.15	0.15	0.01094	0.0004216	0.0000387	0.0003830	0.0102685	0	8
24.96	0.225997	0.15	0.15	0.01092	0.0004242	0.0000422	0.0003820	0.0107051	0	4
25.00	0.22556	0.15	0.15	0.01089	0.0004269	0.0000458	0.0003811	0.0111406	0	0
30.04	0.22555	0.15	0.15	0.01228	0.0004298	0.0000000	0.0004298	0.0004912	0	96
30.08	0.225521	0.15	0.15	0.01228	0.0004298	0.0000001	0.0004297	0.0009823	0	92

30.12	0.225471	0.15	0.15	0.01228	0.0004300	0.0000004	0.0004296	0.0014733	0	88
30.16	0.225403	0.15	0.15	0.01227	0.0004303	0.0000009	0.0004295	0.0019641	0	84
30.20	0.225314	0.15	0.15	0.01226	0.0004308	0.0000015	0.0004292	0.0024547	0	80
30.24	0.225206	0.15	0.15	0.01226	0.0004314	0.0000024	0.0004290	0.0029449	0	76
30.28	0.225079	0.15	0.15	0.01225	0.0004321	0.0000035	0.0004286	0.0034347	0	72
30.32	0.224932	0.15	0.15	0.01223	0.0004329	0.0000047	0.0004282	0.0039241	0	68
30.36	0.224765	0.15	0.15	0.01222	0.0004339	0.0000062	0.0004277	0.0044129	0	64
30.40	0.224579	0.15	0.15	0.01221	0.0004350	0.0000078	0.0004272	0.0049012	0	60
30.44	0.224373	0.15	0.15	0.01219	0.0004362	0.0000096	0.0004266	0.0053887	0	56
30.48	0.224147	0.15	0.15	0.01217	0.0004376	0.0000116	0.0004260	0.0058756	0	52
30.52	0.223903	0.15	0.15	0.01215	0.0004391	0.0000138	0.0004253	0.0063616	0	48
30.56	0.223639	0.15	0.15	0.01213	0.0004408	0.0000162	0.0004246	0.0068468	0	44
30.60	0.223355	0.15	0.15	0.01211	0.0004425	0.0000188	0.0004238	0.0073311	0	40
30.64	0.223052	0.15	0.15	0.01208	0.0004445	0.0000215	0.0004230	0.0078145	0	36
30.68	0.22273	0.15	0.15	0.01206	0.0004465	0.0000244	0.0004221	0.0082969	0	32
30.72	0.222388	0.15	0.15	0.01203	0.0004487	0.0000275	0.0004212	0.0087783	0	28
30.76	0.222028	0.15	0.15	0.01201	0.0004511	0.0000308	0.0004203	0.0092586	0	24
30.80	0.221648	0.15	0.15	0.01198	0.0004536	0.0000343	0.0004193	0.0097378	0	20
30.84	0.221249	0.15	0.15	0.01195	0.0004563	0.0000379	0.0004183	0.0102159	0	16
30.88	0.22083	0.15	0.15	0.01192	0.0004591	0.0000417	0.0004173	0.0106929	0	12
30.92	0.220393	0.15	0.15	0.01189	0.0004620	0.0000457	0.0004163	0.0111686	0	8
30.96	0.219937	0.15	0.15	0.01186	0.0004652	0.0000499	0.0004153	0.0116432	0	4
31.00	0.219462	0.15	0.15	0.01184	0.0004685	0.0000542	0.0004142	0.0121166	0	0
36.04	0.219451	0.15	0.15	0.01348	0.0004719	0.0000000	0.0004719	0.0005393	0	96
36.08	0.219419	0.15	0.15	0.01348	0.0004720	0.0000001	0.0004719	0.0010786	0	92
36.12	0.219365	0.15	0.15	0.01348	0.0004722	0.0000005	0.0004718	0.0016178	0	88
36.16	0.219289	0.15	0.15	0.01347	0.0004726	0.0000010	0.0004716	0.0021568	0	84
36.20	0.219192	0.15	0.15	0.01347	0.0004732	0.0000019	0.0004713	0.0026954	0	80
36.24	0.219074	0.15	0.15	0.01346	0.0004739	0.0000029	0.0004710	0.0032337	0	76
36.28	0.218934	0.15	0.15	0.01345	0.0004748	0.0000042	0.0004706	0.0037715	0	72
36.32	0.218772	0.15	0.15	0.01343	0.0004758	0.0000057	0.0004701	0.0043088	0	68
36.36	0.218589	0.15	0.15	0.01342	0.0004770	0.0000074	0.0004696	0.0048454	0	64
36.40	0.218384	0.15	0.15	0.0134	0.0004784	0.0000094	0.0004690	0.0053814	0	60
36.44	0.218158	0.15	0.15	0.01338	0.0004799	0.0000116	0.0004683	0.0059166	0	56
36.48	0.217911	0.15	0.15	0.01336	0.0004816	0.0000140	0.0004676	0.0064510	0	52
36.52	0.217642	0.15	0.15	0.01334	0.0004834	0.0000166	0.0004668	0.0069844	0	48
36.56	0.217352	0.15	0.15	0.01331	0.0004855	0.0000195	0.0004659	0.0075169	0	44
36.60	0.217041	0.15	0.15	0.01329	0.0004877	0.0000226	0.0004651	0.0080484	0	40
36.64	0.216708	0.15	0.15	0.01326	0.0004900	0.0000259	0.0004641	0.0085788	0	36
36.68	0.216355	0.15	0.15	0.01323	0.0004926	0.0000294	0.0004631	0.0091082	0	32
36.72	0.21598	0.15	0.15	0.0132	0.0004953	0.0000332	0.0004621	0.0096363	0	28
36.76	0.215584	0.15	0.15	0.01317	0.0004982	0.0000371	0.0004611	0.0101633	0	24
36.80	0.215167	0.15	0.15	0.01314	0.0005013	0.0000413	0.0004600	0.0106890	0	20
36.84	0.214729	0.15	0.15	0.01311	0.0005046	0.0000457	0.0004589	0.0112135	0	16
36.88	0.21427	0.15	0.15	0.01308	0.0005081	0.0000503	0.0004578	0.0117367	0	12

36.92	0.21379	0.15	0.15	0.01305	0.0005118	0.0000551	0.0004567	0.0122586	0	8
36.96	0.213289	0.15	0.15	0.01302	0.0005157	0.0000601	0.0004556	0.0127793	0	4
37.00	0.212767	0.15	0.15	0.01298	0.0005198	0.0000653	0.0004545	0.0132987	0	0
42.04	0.212755	0.15	0.15	0.01497	0.0005241	0.0000000	0.0005241	0.0005989	0	96
42.08	0.21272	0.15	0.15	0.01497	0.0005242	0.0000001	0.0005240	0.0011978	0	92
42.12	0.21266	0.15	0.15	0.01497	0.0005245	0.0000006	0.0005239	0.0017966	0	88
42.16	0.212576	0.15	0.15	0.01496	0.0005250	0.0000013	0.0005237	0.0023951	0	84
42.20	0.212468	0.15	0.15	0.01495	0.0005257	0.0000023	0.0005234	0.0029932	0	80
42.24	0.212336	0.15	0.15	0.01494	0.0005266	0.0000036	0.0005230	0.0035909	0	76
42.28	0.212181	0.15	0.15	0.01493	0.0005277	0.0000052	0.0005225	0.0041881	0	72
42.32	0.212001	0.15	0.15	0.01491	0.0005290	0.0000070	0.0005220	0.0047846	0	68
42.36	0.211798	0.15	0.15	0.01489	0.0005305	0.0000092	0.0005213	0.0053804	0	64
42.40	0.211571	0.15	0.15	0.01487	0.0005322	0.0000116	0.0005206	0.0059754	0	60
42.44	0.21132	0.15	0.15	0.01485	0.0005341	0.0000143	0.0005198	0.0065695	0	56
42.48	0.211045	0.15	0.15	0.01483	0.0005363	0.0000173	0.0005190	0.0071626	0	52
42.52	0.210747	0.15	0.15	0.0148	0.0005386	0.0000205	0.0005181	0.0077547	0	48
42.56	0.210425	0.15	0.15	0.01477	0.0005412	0.0000241	0.0005171	0.0083457	0	44
42.60	0.210079	0.15	0.15	0.01475	0.0005439	0.0000279	0.0005161	0.0089355	0	40
42.64	0.20971	0.15	0.15	0.01471	0.0005470	0.0000319	0.0005150	0.0095241	0	36
42.68	0.209318	0.15	0.15	0.01468	0.0005502	0.0000363	0.0005139	0.0101114	0	32
42.72	0.208901	0.15	0.15	0.01465	0.0005537	0.0000409	0.0005128	0.0106974	0	28
42.76	0.208462	0.15	0.15	0.01462	0.0005574	0.0000458	0.0005116	0.0112821	0	24
42.80	0.207999	0.15	0.15	0.01458	0.0005613	0.0000509	0.0005104	0.0118654	0	20
42.84	0.207513	0.15	0.15	0.01455	0.0005655	0.0000563	0.0005092	0.0124473	0	16
42.88	0.207003	0.15	0.15	0.01451	0.0005699	0.0000620	0.0005079	0.0130278	0	12
42.92	0.20647	0.15	0.15	0.01448	0.0005746	0.0000679	0.0005067	0.0136069	0	8
42.96	0.205915	0.15	0.15	0.01444	0.0005796	0.0000741	0.0005055	0.0141846	0	4
43.00	0.205336	0.15	0.15	0.01441	0.0005848	0.0000805	0.0005043	0.0147610	0	0
48.04	0.205322	0.15	0.15	0.01687	0.0005903	0.0000000	0.0005903	0.0006746	0	96
48.08	0.205282	0.15	0.15	0.01686	0.0005904	0.0000002	0.0005903	0.0013492	0	92
48.12	0.205214	0.15	0.15	0.01686	0.0005908	0.0000007	0.0005901	0.0020236	0	88
48.16	0.20512	0.15	0.15	0.01685	0.0005915	0.0000016	0.0005898	0.0026977	0	84
48.20	0.204998	0.15	0.15	0.01684	0.0005924	0.0000029	0.0005895	0.0033714	0	80
48.24	0.20485	0.15	0.15	0.01683	0.0005935	0.0000045	0.0005890	0.0040445	0	76
48.28	0.204675	0.15	0.15	0.01681	0.0005950	0.0000065	0.0005884	0.0047170	0	72
48.32	0.204473	0.15	0.15	0.01679	0.0005967	0.0000089	0.0005878	0.0053887	0	68
48.36	0.204244	0.15	0.15	0.01677	0.0005986	0.0000116	0.0005870	0.0060596	0	64
48.40	0.203988	0.15	0.15	0.01675	0.0006009	0.0000147	0.0005862	0.0067295	0	60
48.44	0.203705	0.15	0.15	0.01672	0.0006034	0.0000181	0.0005853	0.0073984	0	56
48.48	0.203396	0.15	0.15	0.01669	0.0006061	0.0000219	0.0005843	0.0080661	0	52
48.52	0.20306	0.15	0.15	0.01666	0.0006092	0.0000260	0.0005832	0.0087326	0	48
48.56	0.202698	0.15	0.15	0.01663	0.0006126	0.0000305	0.0005821	0.0093978	0	44
48.60	0.202308	0.15	0.15	0.0166	0.0006162	0.0000353	0.0005809	0.0100617	0	40
48.64	0.201893	0.15	0.15	0.01656	0.0006201	0.0000405	0.0005796	0.0107241	0	36
48.68	0.20145	0.15	0.15	0.01652	0.0006244	0.0000460	0.0005784	0.0113851	0	32

48.72	0.200982	0.15	0.15	0.01649	0.0006289	0.0000518	0.0005771	0.0120446	0	28
48.76	0.200487	0.15	0.15	0.01645	0.0006338	0.0000580	0.0005757	0.0127026	0	24
48.80	0.199966	0.15	0.15	0.01641	0.0006389	0.0000645	0.0005744	0.0133590	0	20
48.84	0.199418	0.15	0.15	0.01637	0.0006444	0.0000714	0.0005731	0.0140139	0	16
48.88	0.198845	0.15	0.15	0.01634	0.0006503	0.0000786	0.0005717	0.0146673	0	12
48.92	0.198245	0.15	0.15	0.0163	0.0006565	0.0000861	0.0005704	0.0153193	0	8
48.96	0.197619	0.15	0.15	0.01626	0.0006630	0.0000939	0.0005692	0.0159697	0	4
49.00	0.196967	0.15	0.15	0.01623	0.0006699	0.0001020	0.0005679	0.0166188	0	0
54.04	0.196952	0.15	0.15	0.01935	0.0006772	0.0000000	0.0006772	0.0007740	0	96
54.08	0.196905	0.15	0.15	0.01935	0.0006774	0.0000002	0.0006772	0.0015479	0	92
54.12	0.196828	0.15	0.15	0.01934	0.0006779	0.0000010	0.0006770	0.0023216	0	88
54.16	0.19672	0.15	0.15	0.01933	0.0006788	0.0000022	0.0006767	0.0030949	0	84
54.20	0.19658	0.15	0.15	0.01932	0.0006800	0.0000038	0.0006762	0.0038677	0	80
54.24	0.19641	0.15	0.15	0.0193	0.0006816	0.0000060	0.0006756	0.0046399	0	76
54.28	0.196209	0.15	0.15	0.01928	0.0006836	0.0000086	0.0006749	0.0054113	0	72
54.32	0.195977	0.15	0.15	0.01926	0.0006859	0.0000117	0.0006741	0.0061817	0	68
54.36	0.195715	0.15	0.15	0.01923	0.0006885	0.0000153	0.0006732	0.0069511	0	64
54.40	0.195421	0.15	0.15	0.01921	0.0006915	0.0000193	0.0006722	0.0077193	0	60
54.44	0.195097	0.15	0.15	0.01917	0.0006949	0.0000238	0.0006711	0.0084863	0	56
54.48	0.194742	0.15	0.15	0.01914	0.0006987	0.0000288	0.0006699	0.0092519	0	52
54.52	0.194357	0.15	0.15	0.0191	0.0007029	0.0000342	0.0006686	0.0100161	0	48
54.56	0.193941	0.15	0.15	0.01907	0.0007074	0.0000401	0.0006673	0.0107787	0	44
54.60	0.193495	0.15	0.15	0.01903	0.0007124	0.0000465	0.0006659	0.0115397	0	40
54.64	0.193018	0.15	0.15	0.01899	0.0007177	0.0000533	0.0006645	0.0122991	0	36
54.68	0.192511	0.15	0.15	0.01894	0.0007235	0.0000605	0.0006630	0.0130569	0	32
54.72	0.191974	0.15	0.15	0.0189	0.0007297	0.0000682	0.0006616	0.0138129	0	28
54.76	0.191406	0.15	0.15	0.01886	0.0007364	0.0000763	0.0006601	0.0145673	0	24
54.80	0.190808	0.15	0.15	0.01882	0.0007435	0.0000849	0.0006586	0.0153200	0	20
54.84	0.19018	0.15	0.15	0.01878	0.0007511	0.0000939	0.0006572	0.0160711	0	16
54.88	0.189523	0.15	0.15	0.01874	0.0007591	0.0001033	0.0006558	0.0168206	0	12
54.92	0.188835	0.15	0.15	0.0187	0.0007677	0.0001132	0.0006545	0.0175686	0	8
54.96	0.188117	0.15	0.15	0.01866	0.0007767	0.0001235	0.0006533	0.0183152	0	4
55.00	0.18737	0.15	0.15	0.01863	0.0007863	0.0001342	0.0006521	0.0190604	0	0
60.04	0.187351	0.15	0.15	0.02276	0.0007964	0.0000000	0.0007964	0.0009102	0	96
60.08	0.187297	0.15	0.15	0.02275	0.0007967	0.0000003	0.0007963	0.0018203	0	92
60.12	0.187206	0.15	0.15	0.02275	0.0007974	0.0000013	0.0007961	0.0027301	0	88
60.16	0.187078	0.15	0.15	0.02273	0.0007987	0.0000030	0.0007957	0.0036395	0	84
60.20	0.186915	0.15	0.15	0.02272	0.0008004	0.0000053	0.0007951	0.0045482	0	80
60.24	0.186715	0.15	0.15	0.0227	0.0008027	0.0000083	0.0007944	0.0054561	0	76
60.28	0.186478	0.15	0.15	0.02267	0.0008054	0.0000119	0.0007935	0.0063630	0	72
60.32	0.186206	0.15	0.15	0.02264	0.0008087	0.0000162	0.0007925	0.0072687	0	68
60.36	0.185897	0.15	0.15	0.02261	0.0008125	0.0000211	0.0007914	0.0081732	0	64
60.40	0.185552	0.15	0.15	0.02258	0.0008168	0.0000267	0.0007901	0.0090762	0	60
60.44	0.185171	0.15	0.15	0.02254	0.0008217	0.0000330	0.0007888	0.0099776	0	56
60.48	0.184754	0.15	0.15	0.02249	0.0008271	0.0000398	0.0007873	0.0108774	0	52

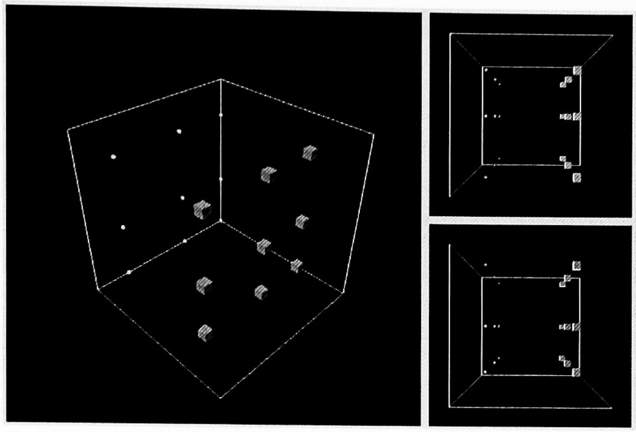
60.52	0.1843	0.15	0.15	0.02245	0.0008331	0.0000473	0.0007858	0.0117755	0	48
60.56	0.183812	0.15	0.15	0.02241	0.0008397	0.0000555	0.0007842	0.0126717	0	44
60.60	0.183287	0.15	0.15	0.02236	0.0008468	0.0000642	0.0007826	0.0135661	0	40
60.64	0.182726	0.15	0.15	0.02231	0.0008546	0.0000736	0.0007810	0.0144586	0	36
60.68	0.18213	0.15	0.15	0.02227	0.0008629	0.0000836	0.0007793	0.0153493	0	32
60.72	0.181498	0.15	0.15	0.02222	0.0008719	0.0000942	0.0007777	0.0162381	0	28
60.76	0.180831	0.15	0.15	0.02218	0.0008816	0.0001055	0.0007761	0.0171251	0	24
60.80	0.180128	0.15	0.15	0.02213	0.0008919	0.0001173	0.0007746	0.0180104	0	20
60.84	0.17939	0.15	0.15	0.02209	0.0009030	0.0001297	0.0007732	0.0188941	0	16
60.88	0.178617	0.15	0.15	0.02206	0.0009148	0.0001428	0.0007720	0.0197763	0	12
60.92	0.177808	0.15	0.15	0.02202	0.0009273	0.0001564	0.0007709	0.0206573	0	8
60.96	0.176964	0.15	0.15	0.022	0.0009406	0.0001707	0.0007699	0.0215373	0	4
61.00	0.176085	0.15	0.15	0.02198	0.0009548	0.0001855	0.0007692	0.0224164	0	0
66.04	0.176063	0.15	0.15	0.02771	0.0009698	0.0000000	0.0009698	0.0011083	0	96
66.08	0.175997	0.15	0.15	0.0277	0.0009702	0.0000005	0.0009697	0.0022165	0	92
66.12	0.175886	0.15	0.15	0.0277	0.0009713	0.0000020	0.0009693	0.0033243	0	88
66.16	0.175731	0.15	0.15	0.02768	0.0009732	0.0000044	0.0009688	0.0044315	0	84
66.20	0.175531	0.15	0.15	0.02766	0.0009759	0.0000079	0.0009681	0.0055379	0	80
66.24	0.175288	0.15	0.15	0.02763	0.0009794	0.0000123	0.0009671	0.0066431	0	76
66.28	0.175	0.15	0.15	0.0276	0.0009836	0.0000177	0.0009660	0.0077471	0	72
66.32	0.174668	0.15	0.15	0.02756	0.0009887	0.0000240	0.0009647	0.0088496	0	68
66.36	0.174292	0.15	0.15	0.02752	0.0009945	0.0000313	0.0009632	0.0099504	0	64
66.40	0.173872	0.15	0.15	0.02748	0.0010012	0.0000396	0.0009616	0.0110494	0	60
66.44	0.173408	0.15	0.15	0.02743	0.0010088	0.0000488	0.0009599	0.0121465	0	56
66.48	0.1729	0.15	0.15	0.02738	0.0010172	0.0000590	0.0009582	0.0132416	0	52
66.52	0.172349	0.15	0.15	0.02732	0.0010265	0.0000701	0.0009564	0.0143345	0	48
66.56	0.171754	0.15	0.15	0.02727	0.0010367	0.0000822	0.0009545	0.0154254	0	44
66.60	0.171115	0.15	0.15	0.02722	0.0010478	0.0000952	0.0009527	0.0165142	0	40
66.64	0.170432	0.15	0.15	0.02717	0.0010600	0.0001091	0.0009509	0.0176009	0	36
66.68	0.169707	0.15	0.15	0.02712	0.0010731	0.0001239	0.0009492	0.0186857	0	32
66.72	0.168938	0.15	0.15	0.02707	0.0010873	0.0001397	0.0009476	0.0197687	0	28
66.76	0.168125	0.15	0.15	0.02703	0.0011025	0.0001563	0.0009462	0.0208501	0	24
66.80	0.16727	0.15	0.15	0.027	0.0011189	0.0001739	0.0009450	0.0219301	0	20
66.84	0.166371	0.15	0.15	0.02698	0.0011365	0.0001924	0.0009441	0.0230091	0	16
66.88	0.165429	0.15	0.15	0.02696	0.0011553	0.0002118	0.0009435	0.0240875	0	12
66.92	0.164444	0.15	0.15	0.02695	0.0011754	0.0002321	0.0009433	0.0251656	0	8
66.96	0.163416	0.15	0.15	0.02696	0.0011969	0.0002533	0.0009435	0.0262439	0	4
67.00	0.162344	0.15	0.15	0.02698	0.0012197	0.0002755	0.0009442	0.0273231	0	0
72.04	0.162316	0.15	0.15	0.03555	0.0012441	0.0000000	0.0012441	0.0014219	0	96
72.08	0.162231	0.15	0.15	0.03554	0.0012448	0.0000008	0.0012440	0.0028435	0	92
72.12	0.162088	0.15	0.15	0.03553	0.0012467	0.0000032	0.0012435	0.0042647	0	88
72.16	0.161889	0.15	0.15	0.03551	0.0012500	0.0000073	0.0012428	0.0056850	0	84
72.20	0.161634	0.15	0.15	0.03548	0.0012546	0.0000129	0.0012417	0.0071041	0	80
72.24	0.161321	0.15	0.15	0.03544	0.0012606	0.0000202	0.0012404	0.0085217	0	76
72.28	0.160952	0.15	0.15	0.0354	0.0012679	0.0000290	0.0012389	0.0099376	0	72

72.32	0.160526	0.15	0.15	0.03535	0.0012767	0.0000395	0.0012371	0.0113514	0	68
72.36	0.160044	0.15	0.15	0.03529	0.0012868	0.0000515	0.0012353	0.0127632	0	64
72.40	0.159505	0.15	0.15	0.03524	0.0012984	0.0000652	0.0012332	0.0141726	0	60
72.44	0.15891	0.15	0.15	0.03518	0.0013115	0.0000803	0.0012312	0.0155796	0	56
72.48	0.158259	0.15	0.15	0.03512	0.0013261	0.0000971	0.0012291	0.0169842	0	52
72.52	0.157551	0.15	0.15	0.03506	0.0013424	0.0001154	0.0012270	0.0183865	0	48
72.56	0.156788	0.15	0.15	0.035	0.0013603	0.0001352	0.0012251	0.0197866	0	44
72.60	0.155969	0.15	0.15	0.03495	0.0013799	0.0001566	0.0012233	0.0211847	0	40
72.64	0.155093	0.15	0.15	0.03491	0.0014014	0.0001795	0.0012219	0.0225811	0	36
72.68	0.154162	0.15	0.15	0.03488	0.0014247	0.0002040	0.0012207	0.0239763	0	32
72.72	0.153175	0.15	0.15	0.03486	0.0014500	0.0002299	0.0012201	0.0253706	0	28
72.76	0.152132	0.15	0.15	0.03486	0.0014774	0.0002575	0.0012199	0.0267649	0	24
72.80	0.151034	0.15	0.15	0.03487	0.0015070	0.0002865	0.0012204	0.0281596	0	20
72.84	0.14988	0.15	0.15	0.0349	0.0015389	0.0003172	0.0012217	0.0295558	0	16
72.88	0.148669	0.15	0.15	0.03496	0.0015732	0.0003494	0.0012238	0.0309544	0	12
72.92	0.147403	0.15	0.15	0.03505	0.0016101	0.0003833	0.0012269	0.0323565	0	8
72.96	0.146081	0.15	0.15	0.03517	0.0016498	0.0004188	0.0012311	0.0337635	0	4
73.00	0.144702	0.15	0.15	0.03533	0.0016925	0.0004560	0.0012365	0.0351766	0	0
78.04	0.144662	0.15	0.15	0.04967	0.0017383	0.0000000	0.0017383	0.0019866	0	96
78.08	0.144543	0.15	0.15	0.04966	0.0017396	0.0000016	0.0017380	0.0039730	0	92
78.12	0.144344	0.15	0.15	0.04964	0.0017437	0.0000063	0.0017373	0.0059585	0	88
78.16	0.144066	0.15	0.15	0.04961	0.0017504	0.0000142	0.0017362	0.0079427	0	84
78.20	0.143709	0.15	0.15	0.04956	0.0017599	0.0000252	0.0017346	0.0099251	0	80
78.24	0.143272	0.15	0.15	0.04951	0.0017721	0.0000394	0.0017327	0.0119054	0	76
78.28	0.142757	0.15	0.15	0.04944	0.0017873	0.0000567	0.0017306	0.0138832	0	72
78.32	0.142162	0.15	0.15	0.04938	0.0018053	0.0000771	0.0017282	0.0158583	0	68
78.36	0.141488	0.15	0.15	0.04931	0.0018264	0.0001006	0.0017258	0.0178306	0	64
78.40	0.140735	0.15	0.15	0.04924	0.0018506	0.0001272	0.0017234	0.0198002	0	60
78.44	0.139904	0.15	0.15	0.04918	0.0018780	0.0001568	0.0017212	0.0217673	0	56
78.48	0.138994	0.15	0.15	0.04912	0.0019089	0.0001895	0.0017193	0.0237322	0	52
78.52	0.138006	0.15	0.15	0.04909	0.0019433	0.0002253	0.0017180	0.0256956	0	48
78.56	0.136938	0.15	0.15	0.04907	0.0019815	0.0002641	0.0017174	0.0276583	0	44
78.60	0.135793	0.15	0.15	0.04907	0.0020236	0.0003060	0.0017176	0.0296213	0	40
78.64	0.134569	0.15	0.15	0.04911	0.0020700	0.0003510	0.0017190	0.0315859	0	36
78.68	0.133266	0.15	0.15	0.04919	0.0021208	0.0003991	0.0017217	0.0335536	0	32
78.72	0.131884	0.15	0.15	0.04932	0.0021764	0.0004503	0.0017261	0.0355262	0	28
78.76	0.130424	0.15	0.15	0.04949	0.0022371	0.0005048	0.0017323	0.0375060	0	24
78.80	0.128884	0.15	0.15	0.04973	0.0023034	0.0005627	0.0017407	0.0394953	0	20
78.84	0.127264	0.15	0.15	0.05004	0.0023755	0.0006240	0.0017515	0.0414971	0	16
78.88	0.125564	0.15	0.15	0.05043	0.0024540	0.0006888	0.0017652	0.0435145	0	12
78.92	0.123782	0.15	0.15	0.05092	0.0025395	0.0007574	0.0017821	0.0455511	0	8
78.96	0.121919	0.15	0.15	0.0515	0.0026324	0.0008300	0.0018025	0.0476111	0	4
79.00	0.119973	0.15	0.15	0.05219	0.0027335	0.0009067	0.0018268	0.0496988	0	0
84.04	0.119908	0.15	0.15	0.08124	0.0028435	0.0000000	0.0028435	0.0032497	0	96
84.08	0.119713	0.15	0.15	0.08123	0.0028473	0.0000042	0.0028430	0.0064989	0	92

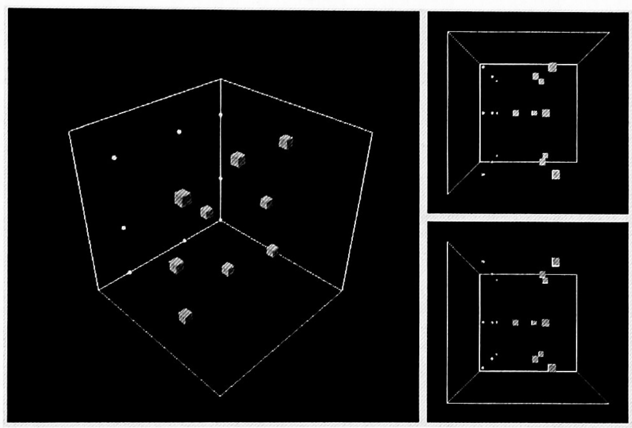
84.12	0.119388	0.15	0.15	0.08119	0.0028586	0.0000169	0.0028417	0.0097485	0	88
84.16	0.118933	0.15	0.15	0.08113	0.0028775	0.0000380	0.0028395	0.0129917	0	84
84.20	0.118349	0.15	0.15	0.08105	0.0029042	0.0000875	0.0028367	0.0162336	0	80
84.24	0.117635	0.15	0.15	0.08096	0.0029389	0.0001054	0.0028335	0.0194718	0	76
84.28	0.116791	0.15	0.15	0.08088	0.0029818	0.0001517	0.0028302	0.0227063	0	72
84.32	0.115818	0.15	0.15	0.08078	0.0030334	0.0002062	0.0028272	0.0259374	0	68
84.36	0.114716	0.15	0.15	0.08071	0.0030941	0.0002691	0.0028250	0.0291659	0	64
84.40	0.113485	0.15	0.15	0.08069	0.0031643	0.0003403	0.0028241	0.0323934	0	80
84.44	0.112125	0.15	0.15	0.08071	0.0032447	0.0004197	0.0028250	0.0356219	0	56
84.48	0.110635	0.15	0.15	0.08081	0.0033359	0.0005076	0.0028283	0.0388543	0	52
84.52	0.109016	0.15	0.15	0.081	0.0034387	0.0006039	0.0028349	0.0420942	0	48
84.58	0.107267	0.15	0.15	0.0813	0.0035541	0.0007088	0.0028453	0.0453460	0	44
84.60	0.105388	0.15	0.15	0.08173	0.0036830	0.0008225	0.0028605	0.0486151	0	40
84.64	0.103378	0.15	0.15	0.08232	0.0038266	0.0009454	0.0028812	0.0519079	0	36
84.68	0.101235	0.15	0.15	0.0831	0.0039861	0.0010778	0.0029083	0.0552317	0	32
84.72	0.098958	0.15	0.15	0.08408	0.0041630	0.0012202	0.0029428	0.0585949	0	28
84.76	0.096546	0.15	0.15	0.0853	0.0043589	0.0013733	0.0029855	0.0620070	0	24
84.80	0.093997	0.15	0.15	0.08678	0.0045754	0.0015379	0.0030374	0.0654783	0	20
84.84	0.091307	0.15	0.15	0.08855	0.0048143	0.0017150	0.0030993	0.0690204	0	16
84.88	0.088473	0.15	0.15	0.09063	0.0050776	0.0019055	0.0031720	0.0726456	0	12
84.92	0.085493	0.15	0.15	0.09303	0.0053671	0.0021110	0.0032561	0.0763669	0	8
84.96	0.082362	0.15	0.15	0.09577	0.0056846	0.0023328	0.0033518	0.0801975	0	4
85.00	0.079075	0.15	0.15	0.09883	0.0060317	0.0025727	0.0034590	0.0841507	0	0
90.04	0.078928	0.15	0.15	0.18312	0.0064092	0.0000000	0.0064092	0.0073249	0	96
90.08	0.078489	0.15	0.15	0.183	0.0064264	0.0000215	0.0064049	0.0146447	0	92
90.12	0.077757	0.15	0.15	0.18263	0.0064778	0.0000858	0.0063920	0.0219499	0	88
90.16	0.076733	0.15	0.15	0.18203	0.0065639	0.0001927	0.0063712	0.0292312	0	84
90.20	0.075419	0.15	0.15	0.18124	0.0066852	0.0003418	0.0063434	0.0364808	0	80
90.24	0.073816	0.15	0.15	0.18028	0.0068421	0.0005323	0.0063098	0.0436920	0	76
90.28	0.071925	0.15	0.15	0.17919	0.0070352	0.0007636	0.0062716	0.0508596	0	72
90.32	0.069748	0.15	0.15	0.178	0.0072646	0.0010347	0.0062300	0.0579795	0	68
90.36	0.067287	0.15	0.15	0.17672	0.0075298	0.0013447	0.0061851	0.0650483	0	64
90.40	0.064545	0.15	0.15	0.17533	0.0078290	0.0016925	0.0061365	0.0720615	0	60
90.44	0.061524	0.15	0.15	0.17376	0.0081588	0.0020771	0.0060817	0.0790119	0	56
90.48	0.058226	0.15	0.15	0.17187	0.0085125	0.0024972	0.0060154	0.0858867	0	52
90.52	0.054655	0.15	0.15	0.1694	0.0088795	0.0029506	0.0059289	0.0926625	0	48
90.56	0.050815	0.15	0.15	0.16595	0.0092427	0.0034345	0.0058081	0.0993004	0	44
90.60	0.046715	0.15	0.15	0.16093	0.0095767	0.0039442	0.0056324	0.1057375	0	40
90.64	0.042362	0.15	0.15	0.15352	0.0098454	0.0044722	0.0053733	0.1118783	0	36
90.68	0.037773	0.15	0.15	0.14267	0.0100001	0.0050067	0.0049934	0.1175851	0	32
90.72	0.032968	0.15	0.15	0.12709	0.0099788	0.0055305	0.0044483	0.1226689	0	28
90.76	0.027977	0.15	0.15	0.10545	0.0097097	0.0060191	0.0036906	0.1268867	0	24
90.80	0.027977	0.15	0.15	0.07656	0.0091196	0.0064401	0.0026795	0.0000000	0	20
90.84	0.027768	0.15	0.15	0.26056	0.0091196	0.0000000	0.0091196	0.0104224	0	16
90.88	0.027145	0.15	0.15	0.2584	0.0090876	0.0000435	0.0090441	0.0207586	0	12

90.92	0.026113	0.15	0.15	0.25188	0.0089881	0.0001724	0.0088157	0.0308337	0	8
90.96	0.026113	0.15	0.15	0.24089	0.0088114	0.0003803	0.0084311	0.0000000	0	4
91.00	0.025912	0.15	0.15	0.25175	0.0088114	0.0000000	0.0088114	0.0100701	0	0
96.04	0.025711	0.15	0.15	0.25072	0.0087751	0.0000000	0.0087751	0.0100287	0	96
96.08	0.025111	0.15	0.15	0.24852	0.0087384	0.0000402	0.0086982	0.0199695	0	92
96.12	0.025111	0.15	0.15	0.24188	0.0086253	0.0001595	0.0084657	0.0000000	0	88

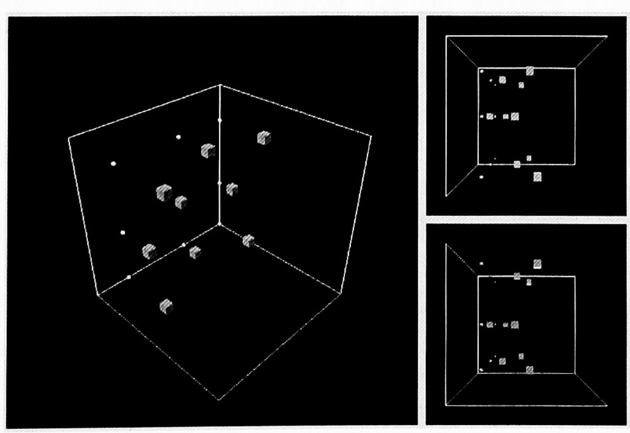
Appendix D: Screenshots of Cos Factor Test



(a) Initial Position at Time 0.00 secs.



(b) Chunxel Position at Time 54 secs.



(c) Chunxel Position at Time 96 secs

Figure 36: Screenshots of the Visual Observation Test for Cos Factor Effect

Appendix E: Data of Proportional Feedback Motion Test

Table 10: Proportional Feedback Motion Test Data (without PFM)[5]

Time	X-coord	Y-coord	Z-coord	Eng.acc	PForce	DForce	TForce	Eng. vel	Coast vel	Time ON
0.04	0.35	0.25	0.25	0.0195	0.000882	0.000000	0.000882	7.80E-04	0	96
0.08	0.3499	0.25	0.25	0.01949	0.000882	0.000000	0.000882	0.0015596	0	92
0.12	0.3499	0.25	0.25	0.01948	0.000883	0.000001	0.000882	0.0023387	0	88
0.16	0.3498	0.25	0.25	0.01945	0.000883	0.000002	0.000881	0.0031188	0	84
0.20	0.3498	0.25	0.25	0.01942	0.000884	0.000004	0.000880	0.0038938	0	80
0.24	0.3494	0.25	0.25	0.01937	0.000884	0.000008	0.000878	0.0048885	0	78
0.28	0.3492	0.25	0.25	0.01932	0.000885	0.000009	0.000878	0.0054414	0	72
0.32	0.349	0.25	0.25	0.01928	0.000886	0.000012	0.000874	0.0082117	0	88
0.36	0.3487	0.25	0.25	0.01919	0.000887	0.000015	0.000871	0.0089791	0	84
0.40	0.3484	0.25	0.25	0.0191	0.000888	0.000019	0.000889	0.0077432	0	80
0.44	0.3481	0.25	0.25	0.01901	0.000889	0.000024	0.000885	0.0085037	0	56
0.48	0.3478	0.25	0.25	0.01891	0.000891	0.000029	0.000882	0.0092803	0	52
0.52	0.3474	0.25	0.25	0.01881	0.000893	0.000034	0.000858	0.0100128	0	48
0.56	0.347	0.25	0.25	0.01889	0.000894	0.000040	0.000854	0.0107803	0	44
0.80	0.3485	0.25	0.25	0.01857	0.000896	0.000048	0.000850	0.011503	0	40
0.84	0.348	0.25	0.25	0.01844	0.000898	0.000053	0.000845	0.0122408	0	38
0.88	0.3455	0.25	0.25	0.0183	0.000700	0.000080	0.000841	0.0129728	0	32
0.72	0.345	0.25	0.25	0.01818	0.000703	0.000087	0.000835	0.0138989	0	28
0.76	0.3444	0.25	0.25	0.01801	0.000705	0.000075	0.000830	0.0144191	0	24
0.80	0.3439	0.25	0.25	0.01785	0.000708	0.000083	0.000825	0.0151331	0	20
0.84	0.3432	0.25	0.25	0.01789	0.000711	0.000092	0.000819	0.0158408	0	18
0.88	0.3428	0.25	0.25	0.01752	0.000714	0.000100	0.000813	0.0185415	0	12
0.92	0.3419	0.25	0.25	0.01735	0.000717	0.000109	0.000807	0.0172354	0	8
0.96	0.3412	0.25	0.25	0.01717	0.000720	0.000119	0.000801	0.0179223	0	4
1.00	0.3405	0.25	0.25	0.01899	0.000723	0.000128	0.000595	0.018802	0	0
8.04	0.3405	0.25	0.25	0.02078	0.000727	0.000000	0.000727	8.31E-04	0	98
8.08	0.3404	0.25	0.25	0.02078	0.000727	0.000000	0.000727	0.0018808	0	92
8.12	0.3403	0.25	0.25	0.02074	0.000727	0.000001	0.000728	0.0024904	0	88
8.16	0.3402	0.25	0.25	0.02071	0.000727	0.000002	0.000725	0.0033189	0	84
8.20	0.3401	0.25	0.25	0.02087	0.000728	0.000004	0.000724	0.0041459	0	80
8.24	0.3399	0.25	0.25	0.02082	0.000729	0.000007	0.000722	0.0049708	0	78
8.28	0.3397	0.25	0.25	0.02058	0.000730	0.000010	0.000720	0.0057933	0	72
8.32	0.3394	0.25	0.25	0.02049	0.000731	0.000013	0.000717	0.008813	0	88
8.36	0.3391	0.25	0.25	0.02041	0.000732	0.000017	0.000714	0.0074293	0	84
8.40	0.3388	0.25	0.25	0.02032	0.000733	0.000022	0.000711	0.008242	0	80

[5] westdata.txt file converted to Excel Format

6.44	0.3385	0.25	0.25	0.02021	0.000735	0.000027	0.000708	0.0090506	0	56
6.48	0.3381	0.25	0.25	0.0201	0.000736	0.000033	0.000704	0.0098547	0	52
6.52	0.3377	0.25	0.25	0.01998	0.000738	0.000039	0.000699	0.010654	0	48
6.56	0.3372	0.25	0.25	0.01985	0.000740	0.000045	0.000695	0.011448	0	44
6.60	0.3368	0.25	0.25	0.01971	0.000742	0.000052	0.000690	0.0122366	0	40
6.64	0.3363	0.25	0.25	0.01957	0.000745	0.000060	0.000685	0.0130192	0	36
6.68	0.3357	0.25	0.25	0.01941	0.000747	0.000068	0.000679	0.0137956	0	32
6.72	0.3352	0.25	0.25	0.01925	0.000750	0.000076	0.000674	0.0145656	0	28
6.76	0.3346	0.25	0.25	0.01908	0.000753	0.000085	0.000668	0.0153288	0	24
6.80	0.3339	0.25	0.25	0.0189	0.000756	0.000094	0.000662	0.0160849	0	20
6.84	0.3333	0.25	0.25	0.01872	0.000759	0.000103	0.000655	0.0168338	0	16
6.88	0.3326	0.25	0.25	0.01853	0.000762	0.000113	0.000649	0.0175752	0	12
6.92	0.3319	0.25	0.25	0.01834	0.000766	0.000124	0.000642	0.0183089	0	8
6.96	0.3311	0.25	0.25	0.01815	0.000769	0.000134	0.000635	0.0190347	0	4
7.00	0.3304	0.25	0.25	0.01794	0.000773	0.000145	0.000628	0.0197525	0	0
12.04	0.3303	0.25	0.25	0.0222	0.000777	0.000000	0.000777	8.88E-04	0	96
12.08	0.3303	0.25	0.25	0.02219	0.000777	0.000000	0.000777	0.0017756	0	92
12.12	0.3302	0.25	0.25	0.02217	0.000777	0.000001	0.000776	0.0026625	0	88
12.16	0.3301	0.25	0.25	0.02214	0.000778	0.000003	0.000775	0.0035481	0	84
12.20	0.3299	0.25	0.25	0.0221	0.000778	0.000005	0.000773	0.004432	0	80
12.24	0.3297	0.25	0.25	0.02204	0.000779	0.000008	0.000771	0.0053135	0	76
12.28	0.3295	0.25	0.25	0.02197	0.000780	0.000011	0.000769	0.0061923	0	72
12.32	0.3292	0.25	0.25	0.02189	0.000781	0.000015	0.000766	0.0070678	0	68
12.36	0.3289	0.25	0.25	0.02179	0.000783	0.000020	0.000763	0.0079396	0	64
12.40	0.3286	0.25	0.25	0.02169	0.000784	0.000025	0.000759	0.0088071	0	60
12.44	0.3282	0.25	0.25	0.02157	0.000786	0.000031	0.000755	0.00967	0	56
12.48	0.3278	0.25	0.25	0.02144	0.000788	0.000037	0.000751	0.0105278	0	52
12.52	0.3274	0.25	0.25	0.02131	0.000790	0.000044	0.000746	0.0113801	0	48
12.56	0.3269	0.25	0.25	0.02116	0.000792	0.000052	0.000741	0.0122265	0	44
12.60	0.3264	0.25	0.25	0.021	0.000795	0.000060	0.000735	0.0130665	0	40
12.64	0.3259	0.25	0.25	0.02083	0.000797	0.000068	0.000729	0.0138999	0	36
12.68	0.3253	0.25	0.25	0.02066	0.000800	0.000077	0.000723	0.0147262	0	32
12.72	0.3247	0.25	0.25	0.02047	0.000803	0.000087	0.000717	0.0155452	0	28
12.76	0.324	0.25	0.25	0.02028	0.000807	0.000097	0.000710	0.0163565	0	24
12.80	0.3234	0.25	0.25	0.02008	0.000810	0.000107	0.000703	0.0171599	0	20
12.84	0.3227	0.25	0.25	0.01988	0.000814	0.000118	0.000696	0.017955	0	16
12.88	0.3219	0.25	0.25	0.01967	0.000817	0.000129	0.000688	0.0187417	0	12
12.92	0.3212	0.25	0.25	0.01945	0.000821	0.000141	0.000681	0.0195198	0	8
12.96	0.3204	0.25	0.25	0.01923	0.000825	0.000152	0.000673	0.0202889	0	4
13.00	0.3195	0.25	0.25	0.019	0.000830	0.000165	0.000665	0.021049	0	0
18.04	0.3195	0.25	0.25	0.02384	0.000834	0.000000	0.000834	9.53E-04	0	96
18.08	0.3195	0.25	0.25	0.02383	0.000834	0.000000	0.000834	0.0019066	0	92
18.12	0.3194	0.25	0.25	0.02381	0.000835	0.000001	0.000833	0.0028589	0	88
18.16	0.3192	0.25	0.25	0.02377	0.000835	0.000003	0.000832	0.0038097	0	84
18.20	0.3191	0.25	0.25	0.02372	0.000836	0.000006	0.000830	0.0047585	0	80

18.24	0.3189	0.25	0.25	0.02365	0.000837	0.000009	0.000828	0.0057046	0	76
18.28	0.3186	0.25	0.25	0.02357	0.000838	0.000013	0.000825	0.0066475	0	72
18.32	0.3183	0.25	0.25	0.02348	0.000839	0.000018	0.000822	0.0075866	0	68
18.36	0.318	0.25	0.25	0.02337	0.000841	0.000023	0.000818	0.0085214	0	64
18.40	0.3176	0.25	0.25	0.02325	0.000843	0.000029	0.000814	0.0094514	0	60
18.44	0.3172	0.25	0.25	0.02312	0.000845	0.000036	0.000809	0.010376	0	56
18.48	0.3168	0.25	0.25	0.02297	0.000847	0.000043	0.000804	0.0112947	0	52
18.52	0.3163	0.25	0.25	0.02281	0.000849	0.000051	0.000798	0.0122071	0	48
18.56	0.3158	0.25	0.25	0.02264	0.000852	0.000060	0.000792	0.0131127	0	44
18.60	0.3153	0.25	0.25	0.02246	0.000855	0.000069	0.000786	0.0140111	0	40
18.64	0.3147	0.25	0.25	0.02227	0.000858	0.000079	0.000779	0.0149018	0	36
18.68	0.3141	0.25	0.25	0.02207	0.000861	0.000089	0.000772	0.0157845	0	32
18.72	0.3135	0.25	0.25	0.02186	0.000865	0.000100	0.000765	0.0166587	0	28
18.76	0.3128	0.25	0.25	0.02164	0.000868	0.000111	0.000757	0.0175242	0	24
18.80	0.3121	0.25	0.25	0.02141	0.000872	0.000123	0.000749	0.0183807	0	20
18.84	0.3113	0.25	0.25	0.02118	0.000876	0.000135	0.000741	0.0192278	0	16
18.88	0.3105	0.25	0.25	0.02094	0.000881	0.000148	0.000733	0.0200652	0	12
18.92	0.3097	0.25	0.25	0.02069	0.000885	0.000161	0.000724	0.0208929	0	8
18.96	0.3088	0.25	0.25	0.02044	0.000890	0.000175	0.000715	0.0217104	0	4
19.00	0.308	0.25	0.25	0.02018	0.000895	0.000189	0.000706	0.0225178	0	0
24.04	0.3079	0.25	0.25	0.02572	0.000900	0.000000	0.000900	0.0010287	0	96
24.08	0.3079	0.25	0.25	0.02571	0.000900	0.000000	0.000900	0.0020571	0	92
24.12	0.3078	0.25	0.25	0.02568	0.000901	0.000002	0.000899	0.0030845	0	88
24.16	0.3076	0.25	0.25	0.02564	0.000901	0.000004	0.000897	0.0041101	0	84
24.20	0.3074	0.25	0.25	0.02558	0.000902	0.000007	0.000895	0.0051334	0	80
24.24	0.3072	0.25	0.25	0.0255	0.000903	0.000011	0.000893	0.0061535	0	76
24.28	0.307	0.25	0.25	0.02541	0.000905	0.000015	0.000889	0.0071699	0	72
24.32	0.3066	0.25	0.25	0.0253	0.000906	0.000021	0.000886	0.008182	0	68
24.36	0.3063	0.25	0.25	0.02518	0.000908	0.000027	0.000881	0.009189	0	64
24.40	0.3059	0.25	0.25	0.02503	0.000910	0.000034	0.000876	0.0101903	0	60
24.44	0.3055	0.25	0.25	0.02488	0.000912	0.000042	0.000871	0.0111854	0	56
24.48	0.305	0.25	0.25	0.02471	0.000915	0.000050	0.000865	0.0121738	0	52
24.52	0.3045	0.25	0.25	0.02452	0.000918	0.000059	0.000858	0.0131547	0	48
24.56	0.304	0.25	0.25	0.02433	0.000921	0.000069	0.000851	0.0141278	0	44
24.60	0.3034	0.25	0.25	0.02412	0.000924	0.000080	0.000844	0.0150925	0	40
24.64	0.3028	0.25	0.25	0.0239	0.000927	0.000091	0.000836	0.0160483	0	36
24.68	0.3021	0.25	0.25	0.02366	0.000931	0.000103	0.000828	0.0169949	0	32
24.72	0.3014	0.25	0.25	0.02342	0.000935	0.000116	0.000820	0.0179317	0	28
24.76	0.3007	0.25	0.25	0.02317	0.000940	0.000129	0.000811	0.0188584	0	24
24.80	0.2999	0.25	0.25	0.02291	0.000944	0.000142	0.000802	0.0197748	0	20
24.84	0.2991	0.25	0.25	0.02264	0.000949	0.000156	0.000792	0.0206803	0	16
24.88	0.2982	0.25	0.25	0.02236	0.000954	0.000171	0.000783	0.0215749	0	12
24.92	0.2974	0.25	0.25	0.02208	0.000959	0.000186	0.000773	0.0224581	0	8
24.96	0.2964	0.25	0.25	0.02179	0.000965	0.000202	0.000763	0.0233299	0	4
25.00	0.2955	0.25	0.25	0.0215	0.000970	0.000218	0.000753	0.02419	0	0

30.04	0.2955	0.25	0.25	0.02789	0.000976	0.000000	0.000976	0.0011157	0	96
30.08	0.2954	0.25	0.25	0.02788	0.000976	0.000000	0.000976	0.0022311	0	92
30.12	0.2953	0.25	0.25	0.02785	0.000977	0.000002	0.000975	0.0033452	0	88
30.16	0.2951	0.25	0.25	0.0278	0.000978	0.000004	0.000973	0.0044573	0	84
30.20	0.2949	0.25	0.25	0.02773	0.000979	0.000008	0.000971	0.0055665	0	80
30.24	0.2947	0.25	0.25	0.02764	0.000980	0.000012	0.000967	0.0066722	0	76
30.28	0.2944	0.25	0.25	0.02753	0.000981	0.000018	0.000964	0.0077734	0	72
30.32	0.2941	0.25	0.25	0.0274	0.000983	0.000024	0.000959	0.0088694	0	68
30.36	0.2937	0.25	0.25	0.02725	0.000985	0.000031	0.000954	0.0099595	0	64
30.40	0.2933	0.25	0.25	0.02709	0.000988	0.000040	0.000948	0.011043	0	60
30.44	0.2928	0.25	0.25	0.0269	0.000990	0.000049	0.000942	0.0121191	0	56
30.48	0.2923	0.25	0.25	0.0267	0.000993	0.000059	0.000935	0.0131873	0	52
30.52	0.2917	0.25	0.25	0.02649	0.000997	0.000070	0.000927	0.0142468	0	48
30.56	0.2912	0.25	0.25	0.02626	0.001000	0.000081	0.000919	0.0152971	0	44
30.60	0.2905	0.25	0.25	0.02601	0.001004	0.000094	0.000910	0.0163375	0	40
30.64	0.2899	0.25	0.25	0.02575	0.001008	0.000107	0.000901	0.0173676	0	36
30.68	0.2891	0.25	0.25	0.02548	0.001012	0.000121	0.000892	0.0183868	0	32
30.72	0.2884	0.25	0.25	0.0252	0.001017	0.000135	0.000882	0.0193947	0	28
30.76	0.2876	0.25	0.25	0.0249	0.001022	0.000150	0.000872	0.0203909	0	24
30.80	0.2867	0.25	0.25	0.0246	0.001027	0.000166	0.000861	0.021375	0	20
30.84	0.2859	0.25	0.25	0.02429	0.001033	0.000183	0.000850	0.0223465	0	16
30.88	0.285	0.25	0.25	0.02397	0.001039	0.000200	0.000839	0.0233053	0	12
30.92	0.284	0.25	0.25	0.02364	0.001045	0.000217	0.000828	0.0242511	0	8
30.96	0.283	0.25	0.25	0.02331	0.001051	0.000235	0.000816	0.0251836	0	4
31.00	0.282	0.25	0.25	0.02298	0.001058	0.000254	0.000804	0.0261026	0	0
36.04	0.282	0.25	0.25	0.03042	0.001065	0.000000	0.001065	0.0012169	0	96
36.08	0.2819	0.25	0.25	0.03041	0.001065	0.000001	0.001064	0.0024333	0	92
36.12	0.2818	0.25	0.25	0.03037	0.001065	0.000002	0.001063	0.0036483	0	88
36.16	0.2816	0.25	0.25	0.03031	0.001066	0.000005	0.001061	0.0048608	0	84
36.20	0.2814	0.25	0.25	0.03023	0.001067	0.000009	0.001058	0.0060699	0	80
36.24	0.2811	0.25	0.25	0.03012	0.001069	0.000015	0.001054	0.0072747	0	76
36.28	0.2808	0.25	0.25	0.02999	0.001071	0.000021	0.001050	0.0084742	0	72
36.32	0.2804	0.25	0.25	0.02983	0.001073	0.000029	0.001044	0.0096675	0	68
36.36	0.28	0.25	0.25	0.02966	0.001075	0.000037	0.001038	0.0108538	0	64
36.40	0.2796	0.25	0.25	0.02946	0.001078	0.000047	0.001031	0.0120322	0	60
36.44	0.2791	0.25	0.25	0.02924	0.001081	0.000058	0.001023	0.0132018	0	56
36.48	0.2785	0.25	0.25	0.029	0.001085	0.000070	0.001015	0.0143619	0	52
36.52	0.2779	0.25	0.25	0.02875	0.001089	0.000083	0.001006	0.0155118	0	48
36.56	0.2773	0.25	0.25	0.02847	0.001093	0.000096	0.000997	0.0166506	0	44
36.60	0.2766	0.25	0.25	0.02818	0.001097	0.000111	0.000986	0.0177779	0	40
36.64	0.2759	0.25	0.25	0.02787	0.001102	0.000126	0.000976	0.0188928	0	36
36.68	0.2751	0.25	0.25	0.02755	0.001107	0.000143	0.000964	0.019995	0	32
36.72	0.2743	0.25	0.25	0.02722	0.001113	0.000160	0.000953	0.0210838	0	28
36.76	0.2734	0.25	0.25	0.02687	0.001118	0.000178	0.000941	0.0221587	0	24
36.80	0.2725	0.25	0.25	0.02652	0.001125	0.000196	0.000928	0.0232194	0	20

36.84	0.2715	0.25	0.25	0.02615	0.001131	0.000216	0.000915	0.0242655	0	16
36.88	0.2705	0.25	0.25	0.02578	0.001138	0.000236	0.000902	0.0252966	0	12
36.92	0.2695	0.25	0.25	0.0254	0.001145	0.000256	0.000889	0.0263124	0	8
36.96	0.2684	0.25	0.25	0.02501	0.001152	0.000277	0.000875	0.0273128	0	4
37.00	0.2673	0.25	0.25	0.02462	0.001160	0.000298	0.000862	0.0282975	0	0
42.04	0.2673	0.25	0.25	0.03337	0.001168	0.000000	0.001168	0.001335	0	96
42.08	0.2672	0.25	0.25	0.03336	0.001168	0.000001	0.001168	0.0026694	0	92
42.12	0.2671	0.25	0.25	0.03332	0.001169	0.000003	0.001166	0.004002	0	88
42.16	0.2669	0.25	0.25	0.03324	0.001170	0.000006	0.001163	0.0053316	0	84
42.20	0.2667	0.25	0.25	0.03314	0.001171	0.000011	0.001160	0.0066572	0	80
42.24	0.2664	0.25	0.25	0.03301	0.001173	0.000018	0.001155	0.0079774	0	76
42.28	0.266	0.25	0.25	0.03285	0.001175	0.000025	0.001150	0.0092913	0	72
42.32	0.2656	0.25	0.25	0.03266	0.001178	0.000035	0.001143	0.0105977	0	68
42.36	0.2652	0.25	0.25	0.03245	0.001181	0.000045	0.001136	0.0118956	0	64
42.40	0.2647	0.25	0.25	0.03221	0.001184	0.000057	0.001127	0.0131839	0	60
42.44	0.2641	0.25	0.25	0.03194	0.001188	0.000070	0.001118	0.0144616	0	56
42.48	0.2635	0.25	0.25	0.03166	0.001192	0.000084	0.001108	0.0157279	0	52
42.52	0.2629	0.25	0.25	0.03135	0.001196	0.000099	0.001097	0.0169818	0	48
42.56	0.2622	0.25	0.25	0.03102	0.001201	0.000115	0.001086	0.0182224	0	44
42.60	0.2614	0.25	0.25	0.03067	0.001206	0.000133	0.001073	0.0194491	0	40
42.64	0.2606	0.25	0.25	0.0303	0.001212	0.000151	0.001060	0.0206611	0	36
42.68	0.2598	0.25	0.25	0.02992	0.001218	0.000171	0.001047	0.0218578	0	32
42.72	0.2589	0.25	0.25	0.02952	0.001224	0.000191	0.001033	0.0230384	0	28
42.76	0.2579	0.25	0.25	0.0291	0.001231	0.000212	0.001019	0.0242026	0	24
42.80	0.2569	0.25	0.25	0.02868	0.001238	0.000234	0.001004	0.0253498	0	20
42.84	0.2559	0.25	0.25	0.02824	0.001246	0.000257	0.000989	0.0264796	0	16
42.88	0.2548	0.25	0.25	0.0278	0.001254	0.000280	0.000973	0.0275916	0	12
42.92	0.2537	0.25	0.25	0.02735	0.001262	0.000305	0.000957	0.0286856	0	8
42.96	0.2525	0.25	0.25	0.02689	0.001270	0.000329	0.000941	0.0297614	0	4
43.00	0.2513	0.25	0.25	0.02643	0.001279	0.000354	0.000925	0.0308187	0	0
48.04	0.2513	0.25	0.25	0.03682	0.001289	0.000000	0.001289	0.0014729	0	96
48.08	0.2512	0.25	0.25	0.03681	0.001289	0.000001	0.001288	0.0029452	0	92
48.12	0.251	0.25	0.25	0.03675	0.001290	0.000003	0.001286	0.0044152	0	88
48.16	0.2508	0.25	0.25	0.03666	0.001291	0.000008	0.001283	0.0058816	0	84
48.20	0.2506	0.25	0.25	0.03653	0.001292	0.000014	0.001279	0.0073429	0	80
48.24	0.2502	0.25	0.25	0.03637	0.001295	0.000022	0.001273	0.0087977	0	76
48.28	0.2499	0.25	0.25	0.03617	0.001297	0.000031	0.001266	0.0102446	0	72
48.32	0.2494	0.25	0.25	0.03594	0.001300	0.000042	0.001258	0.0116824	0	68
48.36	0.2489	0.25	0.25	0.03568	0.001303	0.000055	0.001249	0.0131097	0	64
48.40	0.2484	0.25	0.25	0.03539	0.001307	0.000069	0.001239	0.0145252	0	60
48.44	0.2478	0.25	0.25	0.03506	0.001312	0.000084	0.001227	0.0159277	0	56
48.48	0.2471	0.25	0.25	0.03471	0.001316	0.000101	0.001215	0.0173162	0	52
48.52	0.2464	0.25	0.25	0.03433	0.001322	0.000120	0.001202	0.0186896	0	48
48.56	0.2456	0.25	0.25	0.03393	0.001327	0.000140	0.001188	0.0200469	0	44
48.60	0.2448	0.25	0.25	0.03351	0.001333	0.000161	0.001173	0.0213871	0	40

48.64	0.2439	0.25	0.25	0.03306	0.001340	0.000183	0.001157	0.0227094	0	36
48.68	0.243	0.25	0.25	0.03259	0.001347	0.000206	0.001141	0.024013	0	32
48.72	0.242	0.25	0.25	0.03211	0.001354	0.000231	0.001124	0.0252973	0	28
48.76	0.2409	0.25	0.25	0.03161	0.001362	0.000256	0.001106	0.0265617	0	24
48.80	0.2398	0.25	0.25	0.0311	0.001371	0.000282	0.001088	0.0278055	0	20
48.84	0.2387	0.25	0.25	0.03057	0.001379	0.000309	0.001070	0.0290284	0	16
48.88	0.2375	0.25	0.25	0.03004	0.001388	0.000337	0.001051	0.03023	0	12
48.92	0.2363	0.25	0.25	0.0295	0.001398	0.000366	0.001032	0.0314099	0	8
48.96	0.235	0.25	0.25	0.02895	0.001408	0.000395	0.001013	0.032568	0	4
49.00	0.2337	0.25	0.25	0.0284	0.001418	0.000424	0.000994	0.0337041	0	0
54.04	0.2337	0.25	0.25	0.04083	0.001429	0.000000	0.001429	0.0016333	0	96
54.08	0.2336	0.25	0.25	0.04081	0.001429	0.000001	0.001428	0.0032656	0	92
54.12	0.2334	0.25	0.25	0.04074	0.001430	0.000004	0.001426	0.0048953	0	88
54.16	0.2332	0.25	0.25	0.04063	0.001432	0.000010	0.001422	0.0065203	0	84
54.20	0.2329	0.25	0.25	0.04047	0.001433	0.000017	0.001416	0.008139	0	80
54.24	0.2325	0.25	0.25	0.04026	0.001436	0.000026	0.001409	0.0097496	0	76
54.28	0.2321	0.25	0.25	0.04002	0.001439	0.000038	0.001401	0.0113504	0	72
54.32	0.2316	0.25	0.25	0.03973	0.001442	0.000052	0.001391	0.0129396	0	68
54.36	0.2311	0.25	0.25	0.0394	0.001446	0.000067	0.001379	0.0145157	0	64
54.40	0.2304	0.25	0.25	0.03904	0.001451	0.000084	0.001366	0.0160772	0	60
54.44	0.2298	0.25	0.25	0.03863	0.001456	0.000103	0.001352	0.0176226	0	56
54.48	0.229	0.25	0.25	0.0382	0.001461	0.000124	0.001337	0.0191505	0	52
54.52	0.2282	0.25	0.25	0.03773	0.001467	0.000147	0.001320	0.0206596	0	48
54.56	0.2274	0.25	0.25	0.03723	0.001474	0.000171	0.001303	0.0221487	0	44
54.60	0.2265	0.25	0.25	0.0367	0.001481	0.000196	0.001285	0.0236167	0	40
54.64	0.2255	0.25	0.25	0.03615	0.001488	0.000223	0.001265	0.0250626	0	36
54.68	0.2245	0.25	0.25	0.03557	0.001496	0.000251	0.001245	0.0264855	0	32
54.72	0.2234	0.25	0.25	0.03498	0.001505	0.000281	0.001224	0.0278846	0	28
54.76	0.2222	0.25	0.25	0.03436	0.001514	0.000311	0.001203	0.0292592	0	24
54.80	0.221	0.25	0.25	0.03374	0.001523	0.000342	0.001181	0.0306087	0	20
54.84	0.2198	0.25	0.25	0.0331	0.001533	0.000375	0.001158	0.0319326	0	16
54.88	0.2185	0.25	0.25	0.03245	0.001544	0.000408	0.001136	0.0332304	0	12
54.92	0.2171	0.25	0.25	0.03179	0.001554	0.000442	0.001113	0.034502	0	8
54.96	0.2157	0.25	0.25	0.03113	0.001566	0.000476	0.001089	0.035747	0	4
55.00	0.2143	0.25	0.25	0.03046	0.001577	0.000511	0.001066	0.0369653	0	0
60.04	0.2142	0.25	0.25	0.04541	0.001589	0.000000	0.001589	0.0018163	0	96
60.08	0.2141	0.25	0.25	0.04538	0.001590	0.000001	0.001588	0.0036314	0	92
60.12	0.2139	0.25	0.25	0.04529	0.001590	0.000005	0.001585	0.005443	0	88
60.16	0.2137	0.25	0.25	0.04515	0.001592	0.000012	0.001580	0.0072488	0	84
60.20	0.2134	0.25	0.25	0.04494	0.001594	0.000021	0.001573	0.0090466	0	80
60.24	0.213	0.25	0.25	0.04469	0.001597	0.000033	0.001564	0.010834	0	76
60.28	0.2125	0.25	0.25	0.04437	0.001600	0.000047	0.001553	0.012609	0	72
60.32	0.212	0.25	0.25	0.04401	0.001604	0.000064	0.001540	0.0143694	0	68
60.36	0.2113	0.25	0.25	0.04359	0.001608	0.000083	0.001526	0.0161132	0	64
60.40	0.2107	0.25	0.25	0.04313	0.001613	0.000104	0.001510	0.0178384	0	60

60.44	0.2099	0.25	0.25	0.04262	0.001619	0.000127	0.001492	0.0195433	0	56
60.48	0.2091	0.25	0.25	0.04207	0.001625	0.000153	0.001472	0.0212261	0	52
60.52	0.2082	0.25	0.25	0.04148	0.001632	0.000180	0.001452	0.0228853	0	48
60.56	0.2073	0.25	0.25	0.04085	0.001639	0.000209	0.001430	0.0245193	0	44
60.60	0.2063	0.25	0.25	0.04019	0.001647	0.000240	0.001407	0.0261269	0	40
60.64	0.2052	0.25	0.25	0.0395	0.001655	0.000273	0.001382	0.0277067	0	36
60.68	0.204	0.25	0.25	0.03878	0.001664	0.000307	0.001357	0.0292578	0	32
60.72	0.2028	0.25	0.25	0.03803	0.001674	0.000342	0.001331	0.0307792	0	28
60.76	0.2016	0.25	0.25	0.03727	0.001683	0.000379	0.001304	0.03227	0	24
60.80	0.2003	0.25	0.25	0.03649	0.001694	0.000417	0.001277	0.0337297	0	20
60.84	0.1989	0.25	0.25	0.0357	0.001704	0.000455	0.001249	0.0351576	0	16
60.88	0.1974	0.25	0.25	0.03489	0.001716	0.000494	0.001221	0.0365532	0	12
60.92	0.196	0.25	0.25	0.03408	0.001727	0.000534	0.001193	0.0379164	0	8
60.96	0.1944	0.25	0.25	0.03326	0.001739	0.000575	0.001164	0.0392468	0	4
61.00	0.1928	0.25	0.25	0.03244	0.001752	0.000616	0.001135	0.0405444	0	0
66.04	0.1928	0.25	0.25	0.05041	0.001764	0.000000	0.001764	0.0020162	0	96
66.08	0.1927	0.25	0.25	0.05037	0.001765	0.000002	0.001763	0.0040309	0	92
66.12	0.1925	0.25	0.25	0.05026	0.001765	0.000006	0.001759	0.0060412	0	88
66.16	0.1922	0.25	0.25	0.05007	0.001767	0.000015	0.001752	0.008044	0	84
66.20	0.1918	0.25	0.25	0.04981	0.001769	0.000026	0.001743	0.0100364	0	80
66.24	0.1914	0.25	0.25	0.04948	0.001772	0.000040	0.001732	0.0120157	0	76
66.28	0.1909	0.25	0.25	0.04908	0.001776	0.000058	0.001718	0.013979	0	72
66.32	0.1903	0.25	0.25	0.04861	0.001780	0.000078	0.001702	0.0159235	0	68
66.36	0.1896	0.25	0.25	0.04808	0.001784	0.000101	0.001683	0.0178469	0	64
66.40	0.1888	0.25	0.25	0.04749	0.001790	0.000127	0.001662	0.0197466	0	60
66.44	0.188	0.25	0.25	0.04684	0.001795	0.000156	0.001640	0.0216203	0	56
66.48	0.1871	0.25	0.25	0.04614	0.001802	0.000187	0.001615	0.023466	0	52
66.52	0.1861	0.25	0.25	0.04539	0.001809	0.000220	0.001589	0.0252815	0	48
66.56	0.1851	0.25	0.25	0.04459	0.001816	0.000256	0.001561	0.0270651	0	44
66.60	0.184	0.25	0.25	0.04375	0.001824	0.000293	0.001531	0.0288151	0	40
66.64	0.1828	0.25	0.25	0.04287	0.001833	0.000332	0.001501	0.0305301	0	36
66.68	0.1815	0.25	0.25	0.04197	0.001842	0.000373	0.001469	0.0322088	0	32
66.72	0.1802	0.25	0.25	0.04103	0.001851	0.000415	0.001436	0.0338499	0	28
66.76	0.1788	0.25	0.25	0.04007	0.001861	0.000458	0.001402	0.0354527	0	24
66.80	0.1774	0.25	0.25	0.03909	0.001871	0.000503	0.001368	0.0370162	0	20
66.84	0.1758	0.25	0.25	0.03809	0.001881	0.000548	0.001333	0.0385398	0	16
66.88	0.1743	0.25	0.25	0.03708	0.001892	0.000594	0.001298	0.040023	0	12
66.92	0.1726	0.25	0.25	0.03606	0.001903	0.000641	0.001262	0.0414656	0	8
66.96	0.171	0.25	0.25	0.03504	0.001914	0.000688	0.001226	0.0428672	0	4
67.00	0.1692	0.25	0.25	0.03401	0.001926	0.000735	0.001191	0.0442277	0	0
72.04	0.1692	0.25	0.25	0.05534	0.001937	0.000000	0.001937	0.0022138	0	96
72.08	0.169	0.25	0.25	0.0553	0.001937	0.000002	0.001935	0.0044256	0	92
72.12	0.1688	0.25	0.25	0.05515	0.001938	0.000008	0.001930	0.0066318	0	88
72.16	0.1685	0.25	0.25	0.05492	0.001940	0.000018	0.001922	0.0088284	0	84
72.20	0.1681	0.25	0.25	0.05459	0.001942	0.000031	0.001910	0.0110118	0	80

72.24	0.1676	0.25	0.25	0.05416	0.001944	0.000049	0.001896	0.0131783	0	76
72.28	0.1671	0.25	0.25	0.05365	0.001947	0.000069	0.001878	0.0153245	0	72
72.32	0.1664	0.25	0.25	0.05306	0.001951	0.000094	0.001857	0.0174468	0	68
72.36	0.1657	0.25	0.25	0.05238	0.001955	0.000122	0.001833	0.019542	0	64
72.40	0.1648	0.25	0.25	0.05163	0.001960	0.000153	0.001807	0.0216071	0	60
72.44	0.1639	0.25	0.25	0.0508	0.001965	0.000187	0.001778	0.0236392	0	56
72.48	0.163	0.25	0.25	0.04991	0.001970	0.000224	0.001747	0.0256355	0	52
72.52	0.1619	0.25	0.25	0.04895	0.001976	0.000263	0.001713	0.0275937	0	48
72.56	0.1607	0.25	0.25	0.04794	0.001983	0.000305	0.001678	0.0295113	0	44
72.60	0.1595	0.25	0.25	0.04688	0.001989	0.000348	0.001641	0.0313865	0	40
72.64	0.1582	0.25	0.25	0.04577	0.001996	0.000394	0.001602	0.0332173	0	36
72.68	0.1569	0.25	0.25	0.04462	0.002003	0.000441	0.001562	0.0350022	0	32
72.72	0.1554	0.25	0.25	0.04344	0.002010	0.000490	0.001520	0.0367398	0	28
72.76	0.1539	0.25	0.25	0.04223	0.002018	0.000540	0.001478	0.0384289	0	24
72.80	0.1524	0.25	0.25	0.04099	0.002025	0.000591	0.001435	0.0400687	0	20
72.84	0.1507	0.25	0.25	0.03974	0.002033	0.000642	0.001391	0.0416582	0	16
72.88	0.149	0.25	0.25	0.03847	0.002041	0.000694	0.001346	0.043197	0	12
72.92	0.1473	0.25	0.25	0.03719	0.002048	0.000746	0.001302	0.0446846	0	8
72.96	0.1455	0.25	0.25	0.0359	0.002055	0.000799	0.001257	0.0461208	0	4
73.00	0.1436	0.25	0.25	0.03462	0.002062	0.000851	0.001212	0.0475055	0	0
78.04	0.1435	0.25	0.25	0.05912	0.002069	0.000000	0.002069	0.0023648	0	96
78.08	0.1434	0.25	0.25	0.05906	0.002069	0.000002	0.002067	0.0047271	0	92
78.12	0.1432	0.25	0.25	0.05888	0.002070	0.000009	0.002061	0.0070824	0	88
78.16	0.1428	0.25	0.25	0.05859	0.002071	0.000020	0.002051	0.0094259	0	84
78.20	0.1424	0.25	0.25	0.05818	0.002072	0.000036	0.002036	0.011753	0	80
78.24	0.1419	0.25	0.25	0.05765	0.002073	0.000055	0.002018	0.0140591	0	76
78.28	0.1413	0.25	0.25	0.05702	0.002075	0.000079	0.001996	0.01634	0	72
78.32	0.1406	0.25	0.25	0.05628	0.002077	0.000107	0.001970	0.0185913	0	68
78.36	0.1398	0.25	0.25	0.05545	0.002079	0.000138	0.001941	0.0208091	0	64
78.40	0.1389	0.25	0.25	0.05451	0.002081	0.000173	0.001908	0.0229896	0	60
78.44	0.138	0.25	0.25	0.05349	0.002084	0.000211	0.001872	0.0251292	0	56
78.48	0.1369	0.25	0.25	0.05238	0.002086	0.000253	0.001833	0.0272246	0	52
78.52	0.1358	0.25	0.25	0.0512	0.002089	0.000296	0.001792	0.0292727	0	48
78.56	0.1346	0.25	0.25	0.04995	0.002091	0.000343	0.001748	0.0312709	0	44
78.60	0.1333	0.25	0.25	0.04864	0.002094	0.000391	0.001702	0.0332166	0	40
78.64	0.1319	0.25	0.25	0.04727	0.002096	0.000441	0.001655	0.0351075	0	36
78.68	0.1305	0.25	0.25	0.04586	0.002098	0.000493	0.001605	0.0369418	0	32
78.72	0.129	0.25	0.25	0.0444	0.002100	0.000546	0.001554	0.0387178	0	28
78.76	0.1274	0.25	0.25	0.04291	0.002101	0.000600	0.001502	0.0404341	0	24
78.80	0.1257	0.25	0.25	0.04138	0.002102	0.000654	0.001448	0.0420894	0	20
78.84	0.124	0.25	0.25	0.03984	0.002103	0.000709	0.001394	0.043683	0	16
78.88	0.1222	0.25	0.25	0.03827	0.002103	0.000763	0.001340	0.045214	0	12
78.92	0.1204	0.25	0.25	0.0367	0.002102	0.000818	0.001284	0.0466819	0	8
78.96	0.1185	0.25	0.25	0.03511	0.002101	0.000872	0.001229	0.0480865	0	4
79.00	0.1165	0.25	0.25	0.03353	0.002098	0.000925	0.001173	0.0494275	0	0

84.04	0.1165	0.25	0.25	0.05986	0.002095	0.000000	0.002095	0.0023943	0	96
84.08	0.1164	0.25	0.25	0.05979	0.002095	0.000002	0.002093	0.0047859	0	92
84.12	0.1161	0.25	0.25	0.05958	0.002095	0.000009	0.002085	0.0071692	0	88
84.16	0.1158	0.25	0.25	0.05925	0.002094	0.000021	0.002074	0.0095391	0	84
84.20	0.1154	0.25	0.25	0.05877	0.002093	0.000036	0.002057	0.01189	0	80
84.24	0.1148	0.25	0.25	0.05817	0.002093	0.000057	0.002036	0.0142168	0	76
84.28	0.1142	0.25	0.25	0.05744	0.002091	0.000081	0.002010	0.0165145	0	72
84.32	0.1135	0.25	0.25	0.05659	0.002090	0.000109	0.001981	0.0187783	0	68
84.36	0.1127	0.25	0.25	0.05563	0.002088	0.000141	0.001947	0.0210034	0	64
84.40	0.1118	0.25	0.25	0.05455	0.002086	0.000176	0.001909	0.0231855	0	60
84.44	0.1109	0.25	0.25	0.05338	0.002083	0.000215	0.001868	0.0253205	0	56
84.48	0.1098	0.25	0.25	0.0521	0.002080	0.000256	0.001824	0.0274046	0	52
84.52	0.1087	0.25	0.25	0.05074	0.002076	0.000300	0.001776	0.0294343	0	48
84.56	0.1075	0.25	0.25	0.0493	0.002072	0.000347	0.001726	0.0314064	0	44
84.60	0.1062	0.25	0.25	0.04779	0.002067	0.000395	0.001673	0.0333179	0	40
84.64	0.1048	0.25	0.25	0.04621	0.002061	0.000444	0.001617	0.0351664	0	36
84.68	0.1033	0.25	0.25	0.04458	0.002055	0.000495	0.001560	0.0369495	0	32
84.72	0.1018	0.25	0.25	0.0429	0.002047	0.000546	0.001501	0.0386653	0	28
84.76	0.1003	0.25	0.25	0.04117	0.002039	0.000598	0.001441	0.0403122	0	24

Table 11: Proportional Feedback Motion Test Data (with PFM)[6]

Time	X-coord	Y-coord	Z-coord	Eng.acc	PForce	DForce	TForce	Eng. vel	Coast vel	Time ON
0.04	0.349984	0.25	0.25	0.019497	0.000682	0.000000	0.000682	0.000780	0	96
0.08	0.349938	0.25	0.25	0.019492	0.000682	0.000000	0.000682	0.001560	0	92
0.12	0.34986	0.25	0.25	0.019478	0.000683	0.000001	0.000682	0.002339	0	88
0.16	0.349751	0.25	0.25	0.019453	0.000683	0.000002	0.000681	0.003117	0	84
0.20	0.34961	0.25	0.25	0.019418	0.000684	0.000004	0.000680	0.003894	0	80
0.24	0.349439	0.25	0.25	0.019374	0.000684	0.000006	0.000678	0.004669	0	76
0.28	0.349237	0.25	0.25	0.019321	0.000685	0.000009	0.000676	0.005441	0	72
0.32	0.349004	0.25	0.25	0.019257	0.000686	0.000012	0.000674	0.006212	0	68
0.36	0.34874	0.25	0.25	0.019185	0.000687	0.000015	0.000671	0.006979	0	64
0.40	0.348446	0.25	0.25	0.019104	0.000688	0.000019	0.000869	0.007743	0	60
0.44	0.348121	0.25	0.25	0.019013	0.000689	0.000024	0.000865	0.008504	0	56
0.48	0.347765	0.25	0.25	0.018914	0.000691	0.000029	0.000662	0.009260	0	52
0.52	0.34738	0.25	0.25	0.018807	0.000693	0.000034	0.000658	0.010013	0	48
0.56	0.346964	0.25	0.25	0.018692	0.000694	0.000040	0.000654	0.010760	0	44
0.60	0.346519	0.25	0.25	0.018569	0.000696	0.000048	0.000650	0.011503	0	40
0.64	0.346044	0.25	0.25	0.018438	0.000698	0.000053	0.000645	0.012241	0	36
0.68	0.34554	0.25	0.25	0.018301	0.000700	0.000060	0.000641	0.012973	0	32
0.72	0.345007	0.25	0.25	0.018157	0.000703	0.000067	0.000635	0.013699	0	28
0.76	0.344444	0.25	0.25	0.018006	0.000705	0.000075	0.000630	0.014419	0	24
0.80	0.343853	0.25	0.25	0.01785	0.000708	0.000083	0.000625	0.015133	0	20
0.84	0.343234	0.25	0.25	0.017688	0.000711	0.000092	0.000619	0.015841	0	16
0.88	0.342586	0.25	0.25	0.017521	0.000714	0.000100	0.000613	0.016541	0	12
0.92	0.341911	0.25	0.25	0.017349	0.000717	0.000109	0.000607	0.017235	0	8
0.96	0.341207	0.25	0.25	0.017172	0.000720	0.000119	0.000601	0.017922	0	4
1.00	0.340477	0.25	0.25	0.018992	0.000723	0.000128	0.000595	0.018602	0	0
6.04	0.34046	0.25	0.25	0.020763	0.000727	0.000000	0.000727	0.000831	0	96
6.08	0.340411	0.25	0.25	0.020757	0.000727	0.000000	0.000727	0.001861	0	92
6.12	0.340327	0.25	0.25	0.020741	0.000727	0.000001	0.000726	0.002490	0	88
6.16	0.340211	0.25	0.25	0.020713	0.000727	0.000002	0.000725	0.003319	0	84
6.20	0.340062	0.25	0.25	0.020674	0.000728	0.000004	0.000724	0.004146	0	80
6.24	0.33988	0.25	0.25	0.020623	0.000729	0.000007	0.000722	0.004971	0	76
6.28	0.339664	0.25	0.25	0.020563	0.000730	0.000010	0.000720	0.005793	0	72
6.32	0.339416	0.25	0.25	0.020491	0.000731	0.000013	0.000717	0.006613	0	68
6.36	0.339135	0.25	0.25	0.020409	0.000732	0.000017	0.000714	0.007429	0	64
6.40	0.338822	0.25	0.25	0.020317	0.000733	0.000022	0.000711	0.008242	0	60
6.44	0.338476	0.25	0.25	0.020215	0.000735	0.000027	0.000708	0.009051	0	56
6.48	0.338098	0.25	0.25	0.020103	0.000736	0.000033	0.000704	0.009855	0	52
6.52	0.337688	0.25	0.25	0.019982	0.000738	0.000039	0.000699	0.010654	0	48

[6] westdata.txt file converted to Excel Format

6.56	0.337246	0.25	0.25	0.019852	0.000740	0.000045	0.000695	0.011448	0	44
6.60	0.336772	0.25	0.25	0.019713	0.000742	0.000052	0.000690	0.012237	0	40
6.64	0.336267	0.25	0.25	0.019566	0.000745	0.000060	0.000685	0.013019	0	36
6.68	0.335731	0.25	0.25	0.019411	0.000747	0.000068	0.000679	0.013796	0	32
6.72	0.335163	0.25	0.25	0.019249	0.000750	0.000076	0.000674	0.014566	0	28
6.76	0.334566	0.25	0.25	0.01908	0.000753	0.000085	0.000668	0.015329	0	24
6.80	0.333937	0.25	0.25	0.018904	0.000756	0.000094	0.000662	0.016085	0	20
6.84	0.333279	0.25	0.25	0.018722	0.000759	0.000103	0.000655	0.016834	0	16
6.88	0.332591	0.25	0.25	0.018535	0.000762	0.000113	0.000649	0.017575	0	12
6.92	0.331873	0.25	0.25	0.018342	0.000766	0.000124	0.000642	0.018309	0	8
6.96	0.331126	0.25	0.25	0.018145	0.000769	0.000134	0.000635	0.019035	0	4
7.00	0.33035	0.25	0.25	0.017944	0.000773	0.000145	0.000628	0.019753	0	0
12.04	0.330333	0.25	0.25	0.022198	0.000777	0.000000	0.000777	0.000888	0	96
12.08	0.330279	0.25	0.25	0.022192	0.000777	0.000000	0.000777	0.001776	0	92
12.12	0.330191	0.25	0.25	0.022173	0.000777	0.000001	0.000776	0.002663	0	88
12.16	0.330066	0.25	0.25	0.022141	0.000778	0.000003	0.000775	0.003548	0	84
12.20	0.329907	0.25	0.25	0.022096	0.000778	0.000005	0.000773	0.004432	0	80
12.24	0.329712	0.25	0.25	0.022039	0.000779	0.000008	0.000771	0.005314	0	76
12.28	0.329482	0.25	0.25	0.021969	0.000780	0.000011	0.000769	0.006192	0	72
12.32	0.329217	0.25	0.25	0.021888	0.000781	0.000015	0.000766	0.007068	0	68
12.36	0.328917	0.25	0.25	0.021794	0.000783	0.000020	0.000763	0.007940	0	64
12.40	0.328582	0.25	0.25	0.021689	0.000784	0.000025	0.000759	0.008807	0	60
12.44	0.328212	0.25	0.25	0.021572	0.000786	0.000031	0.000755	0.009670	0	56
12.48	0.327808	0.25	0.25	0.021445	0.000788	0.000037	0.000751	0.010528	0	52
12.52	0.32737	0.25	0.25	0.021307	0.000790	0.000044	0.000746	0.011380	0	48
12.56	0.326898	0.25	0.25	0.021159	0.000792	0.000052	0.000741	0.012226	0	44
12.60	0.326392	0.25	0.25	0.021001	0.000795	0.000060	0.000735	0.013067	0	40
12.64	0.325853	0.25	0.25	0.020834	0.000797	0.000068	0.000729	0.013900	0	36
12.68	0.32528	0.25	0.25	0.020658	0.000800	0.000077	0.000723	0.014726	0	32
12.72	0.324675	0.25	0.25	0.020475	0.000803	0.000087	0.000717	0.015545	0	28
12.76	0.324037	0.25	0.25	0.020283	0.000807	0.000097	0.000710	0.016357	0	24
12.80	0.323366	0.25	0.25	0.020084	0.000810	0.000107	0.000703	0.017160	0	20
12.84	0.322664	0.25	0.25	0.019879	0.000814	0.000118	0.000696	0.017955	0	16
12.88	0.32193	0.25	0.25	0.019668	0.000817	0.000129	0.000688	0.018742	0	12
12.92	0.321165	0.25	0.25	0.019451	0.000821	0.000141	0.000681	0.019520	0	8
12.96	0.320369	0.25	0.25	0.019229	0.000825	0.000152	0.000673	0.020289	0	4
13.00	0.319542	0.25	0.25	0.019003	0.000830	0.000165	0.000665	0.021049	0	0
18.04	0.319523	0.25	0.25	0.023837	0.000834	0.000000	0.000834	0.000953	0	96
18.08	0.319466	0.25	0.25	0.023829	0.000834	0.000000	0.000834	0.001907	0	92
18.12	0.31937	0.25	0.25	0.023807	0.000835	0.000001	0.000833	0.002859	0	88
18.16	0.319237	0.25	0.25	0.02377	0.000835	0.000003	0.000832	0.003810	0	84
18.20	0.319066	0.25	0.25	0.023719	0.000836	0.000006	0.000830	0.004758	0	80
18.24	0.318856	0.25	0.25	0.023653	0.000837	0.000009	0.000828	0.005705	0	76
18.28	0.318609	0.25	0.25	0.023572	0.000838	0.000013	0.000825	0.006647	0	72
18.32	0.318325	0.25	0.25	0.023478	0.000839	0.000018	0.000822	0.007587	0	68

18.36	0.318002	0.25	0.25	0.02337	0.000841	0.000023	0.000818	0.008521	0	64
18.40	0.317643	0.25	0.25	0.023249	0.000843	0.000029	0.000814	0.009451	0	60
18.44	0.317246	0.25	0.25	0.023115	0.000845	0.000036	0.000809	0.010376	0	56
18.48	0.316813	0.25	0.25	0.022969	0.000847	0.000043	0.000804	0.011295	0	52
18.52	0.316343	0.25	0.25	0.02281	0.000849	0.000051	0.000798	0.012207	0	48
18.56	0.315837	0.25	0.25	0.02264	0.000852	0.000060	0.000792	0.013113	0	44
18.60	0.315294	0.25	0.25	0.022459	0.000855	0.000069	0.000786	0.014011	0	40
18.64	0.314716	0.25	0.25	0.022268	0.000858	0.000079	0.000779	0.014902	0	36
18.68	0.314102	0.25	0.25	0.022067	0.000861	0.000089	0.000772	0.015784	0	32
18.72	0.313453	0.25	0.25	0.021856	0.000865	0.000100	0.000765	0.016659	0	28
18.76	0.31277	0.25	0.25	0.021638	0.000868	0.000111	0.000757	0.017524	0	24
18.80	0.312052	0.25	0.25	0.021411	0.000872	0.000123	0.000749	0.018381	0	20
18.84	0.311299	0.25	0.25	0.021177	0.000876	0.000135	0.000741	0.019228	0	16
18.88	0.310513	0.25	0.25	0.020937	0.000881	0.000148	0.000733	0.020065	0	12
18.92	0.309694	0.25	0.25	0.020691	0.000885	0.000161	0.000724	0.020893	0	8
18.96	0.308842	0.25	0.25	0.020439	0.000890	0.000175	0.000715	0.021710	0	4
19.00	0.307958	0.25	0.25	0.020183	0.000895	0.000189	0.000706	0.022518	0	0
24.04	0.307937	0.25	0.25	0.025718	0.000900	0.000000	0.000900	0.001029	0	96
24.08	0.307875	0.25	0.25	0.02571	0.000900	0.000000	0.000900	0.002057	0	92
24.12	0.307773	0.25	0.25	0.025684	0.000901	0.000002	0.000899	0.003084	0	88
24.16	0.307629	0.25	0.25	0.025641	0.000901	0.000004	0.000897	0.004110	0	84
24.20	0.307444	0.25	0.25	0.025581	0.000902	0.000007	0.000895	0.005133	0	80
24.24	0.307218	0.25	0.25	0.025504	0.000903	0.000011	0.000893	0.006154	0	76
24.28	0.306952	0.25	0.25	0.02541	0.000905	0.000015	0.000889	0.007170	0	72
24.32	0.306645	0.25	0.25	0.025301	0.000906	0.000021	0.000886	0.008182	0	68
24.36	0.306297	0.25	0.25	0.025175	0.000908	0.000027	0.000881	0.009189	0	64
24.40	0.30591	0.25	0.25	0.025034	0.000910	0.000034	0.000876	0.010190	0	60
24.44	0.305482	0.25	0.25	0.024878	0.000912	0.000042	0.000871	0.011185	0	56
24.48	0.305015	0.25	0.25	0.024708	0.000915	0.000050	0.000865	0.012174	0	52
24.52	0.304508	0.25	0.25	0.024524	0.000918	0.000059	0.000858	0.013155	0	48
24.56	0.303963	0.25	0.25	0.024327	0.000921	0.000069	0.000851	0.014128	0	44
24.60	0.303378	0.25	0.25	0.024117	0.000924	0.000080	0.000844	0.015092	0	40
24.64	0.302755	0.25	0.25	0.023896	0.000927	0.000091	0.000836	0.016048	0	36
24.68	0.302095	0.25	0.25	0.023663	0.000931	0.000103	0.000828	0.016995	0	32
24.72	0.301396	0.25	0.25	0.023421	0.000935	0.000116	0.000820	0.017932	0	28
24.76	0.30066	0.25	0.25	0.023169	0.000940	0.000129	0.000811	0.018858	0	24
24.80	0.299888	0.25	0.25	0.022908	0.000944	0.000142	0.000802	0.019775	0	20
24.84	0.299079	0.25	0.25	0.022639	0.000949	0.000156	0.000792	0.020680	0	16
24.88	0.298233	0.25	0.25	0.022363	0.000954	0.000171	0.000783	0.021575	0	12
24.92	0.297353	0.25	0.25	0.022081	0.000959	0.000186	0.000773	0.022458	0	8
24.96	0.296437	0.25	0.25	0.021794	0.000965	0.000202	0.000763	0.023330	0	4
25.00	0.295487	0.25	0.25	0.021502	0.000970	0.000218	0.000753	0.024190	0	0
30.04	0.295464	0.25	0.25	0.027894	0.000976	0.000000	0.000976	0.001116	0	96
30.08	0.295397	0.25	0.25	0.027884	0.000976	0.000000	0.000976	0.002231	0	92
30.12	0.295286	0.25	0.25	0.027853	0.000977	0.000002	0.000975	0.003345	0	88

30.16	0.29513	0.25	0.25	0.027802	0.000978	0.000004	0.000973	0.004457	0	84
30.20	0.294929	0.25	0.25	0.027731	0.000979	0.000008	0.000971	0.005567	0	80
30.24	0.294685	0.25	0.25	0.02764	0.000980	0.000012	0.000967	0.006672	0	76
30.28	0.294396	0.25	0.25	0.02753	0.000981	0.000018	0.000964	0.007773	0	72
30.32	0.294063	0.25	0.25	0.027401	0.000983	0.000024	0.000959	0.008869	0	68
30.36	0.293686	0.25	0.25	0.027253	0.000985	0.000031	0.000954	0.009960	0	64
30.40	0.293266	0.25	0.25	0.027087	0.000988	0.000040	0.000948	0.011043	0	60
30.44	0.292803	0.25	0.25	0.026904	0.000990	0.000049	0.000942	0.012119	0	56
30.48	0.292297	0.25	0.25	0.026704	0.000993	0.000059	0.000935	0.013187	0	52
30.52	0.291748	0.25	0.25	0.026488	0.000997	0.000070	0.000927	0.014247	0	48
30.56	0.291157	0.25	0.25	0.026257	0.001000	0.000081	0.000919	0.015297	0	44
30.60	0.290524	0.25	0.25	0.026011	0.001004	0.000094	0.000910	0.016338	0	40
30.64	0.28985	0.25	0.25	0.025752	0.001008	0.000107	0.000901	0.017368	0	36
30.68	0.289135	0.25	0.25	0.025481	0.001012	0.000121	0.000892	0.018387	0	32
30.72	0.28838	0.25	0.25	0.025198	0.001017	0.000135	0.000882	0.019395	0	28
30.76	0.287584	0.25	0.25	0.024904	0.001022	0.000150	0.000872	0.020391	0	24
30.80	0.286749	0.25	0.25	0.024601	0.001027	0.000166	0.000861	0.021375	0	20
30.84	0.285874	0.25	0.25	0.024289	0.001033	0.000183	0.000850	0.022347	0	16
30.88	0.284961	0.25	0.25	0.02397	0.001039	0.000200	0.000839	0.023305	0	12
30.92	0.28401	0.25	0.25	0.023644	0.001045	0.000217	0.000828	0.024251	0	8
30.96	0.283021	0.25	0.25	0.023312	0.001051	0.000235	0.000816	0.025184	0	4
31.00	0.281996	0.25	0.25	0.022976	0.001058	0.000254	0.000804	0.026103	0	0
36.04	0.281971	0.25	0.25	0.030422	0.001065	0.000000	0.001065	0.001217	0	96
36.08	0.281898	0.25	0.25	0.03041	0.001065	0.000001	0.001064	0.002433	0	92
36.12	0.281777	0.25	0.25	0.030374	0.001065	0.000002	0.001063	0.003648	0	88
36.16	0.281606	0.25	0.25	0.030313	0.001066	0.000005	0.001061	0.004861	0	84
36.20	0.281388	0.25	0.25	0.030228	0.001067	0.000009	0.001058	0.006070	0	80
36.24	0.281121	0.25	0.25	0.03012	0.001069	0.000015	0.001054	0.007275	0	76
36.28	0.280806	0.25	0.25	0.029988	0.001071	0.000021	0.001050	0.008474	0	72
36.32	0.280443	0.25	0.25	0.029833	0.001073	0.000029	0.001044	0.009668	0	68
36.36	0.280033	0.25	0.25	0.029657	0.001075	0.000037	0.001038	0.010854	0	64
36.40	0.279575	0.25	0.25	0.029459	0.001078	0.000047	0.001031	0.012032	0	60
36.44	0.27907	0.25	0.25	0.029241	0.001081	0.000058	0.001023	0.013202	0	56
36.48	0.278519	0.25	0.25	0.029003	0.001085	0.000070	0.001015	0.014362	0	52
36.52	0.277922	0.25	0.25	0.028746	0.001089	0.000083	0.001006	0.015512	0	48
36.56	0.277278	0.25	0.25	0.028472	0.001093	0.000096	0.000997	0.016651	0	44
36.60	0.27659	0.25	0.25	0.028181	0.001097	0.000111	0.000986	0.017778	0	40
36.64	0.275856	0.25	0.25	0.027874	0.001102	0.000126	0.000976	0.018893	0	36
36.68	0.275079	0.25	0.25	0.027554	0.001107	0.000143	0.000964	0.019995	0	32
36.72	0.274257	0.25	0.25	0.02722	0.001113	0.000160	0.000953	0.021084	0	28
36.76	0.273392	0.25	0.25	0.026874	0.001118	0.000178	0.000941	0.022159	0	24
36.80	0.272485	0.25	0.25	0.026517	0.001125	0.000196	0.000928	0.023219	0	20
36.84	0.271535	0.25	0.25	0.026151	0.001131	0.000216	0.000915	0.024265	0	16
36.88	0.270544	0.25	0.25	0.025777	0.001138	0.000236	0.000902	0.025297	0	12
36.92	0.269511	0.25	0.25	0.025396	0.001145	0.000256	0.000889	0.026312	0	8

36.96	0.266439	0.25	0.25	0.025009	0.001152	0.000277	0.000875	0.027313	0	4
37.00	0.267327	0.25	0.25	0.024618	0.001160	0.000298	0.000862	0.028297	0	0
42.04	0.2673	0.25	0.25	0.033374	0.001168	0.000000	0.001168	0.001335	0	96
42.08	0.26722	0.25	0.25	0.03336	0.001168	0.000001	0.001168	0.002669	0	92
42.12	0.267086	0.25	0.25	0.033315	0.001169	0.000003	0.001166	0.004002	0	88
42.16	0.2669	0.25	0.25	0.033241	0.001170	0.000006	0.001163	0.005332	0	84
42.20	0.26666	0.25	0.25	0.033138	0.001171	0.000011	0.001160	0.006657	0	80
42.24	0.266367	0.25	0.25	0.033007	0.001173	0.000018	0.001155	0.007977	0	76
42.28	0.266022	0.25	0.25	0.032847	0.001175	0.000025	0.001150	0.009291	0	72
42.32	0.265624	0.25	0.25	0.03266	0.001178	0.000035	0.001143	0.010598	0	68
42.36	0.265174	0.25	0.25	0.032447	0.001181	0.000045	0.001136	0.011896	0	64
42.40	0.264673	0.25	0.25	0.032207	0.001184	0.000057	0.001127	0.013184	0	60
42.44	0.26412	0.25	0.25	0.031944	0.001188	0.000070	0.001118	0.014462	0	56
42.48	0.263516	0.25	0.25	0.031656	0.001192	0.000084	0.001108	0.015728	0	52
42.52	0.262862	0.25	0.25	0.031347	0.001196	0.000099	0.001097	0.016982	0	48
42.56	0.262158	0.25	0.25	0.031017	0.001201	0.000115	0.001086	0.018222	0	44
42.60	0.261404	0.25	0.25	0.030667	0.001206	0.000133	0.001073	0.019449	0	40
42.64	0.260602	0.25	0.25	0.0303	0.001212	0.000151	0.001060	0.020661	0	36
42.68	0.259752	0.25	0.25	0.029916	0.001218	0.000171	0.001047	0.021858	0	32
42.72	0.258854	0.25	0.25	0.029517	0.001224	0.000191	0.001033	0.023038	0	28
42.76	0.257909	0.25	0.25	0.029104	0.001231	0.000212	0.001019	0.024203	0	24
42.80	0.256916	0.25	0.25	0.02868	0.001238	0.000234	0.001004	0.025350	0	20
42.64	0.255881	0.25	0.25	0.028245	0.001246	0.000257	0.000989	0.026480	0	16
42.88	0.2548	0.25	0.25	0.027801	0.001254	0.000280	0.000973	0.027592	0	12
42.92	0.253674	0.25	0.25	0.02735	0.001262	0.000305	0.000957	0.028686	0	8
42.96	0.252505	0.25	0.25	0.026894	0.001270	0.000329	0.000941	0.029761	0	4
43.00	0.251294	0.25	0.25	0.026433	0.001279	0.000354	0.000925	0.030819	0	0
48.04	0.251264	0.25	0.25	0.036824	0.001289	0.000000	0.001289	0.001473	0	96
48.08	0.251176	0.25	0.25	0.036805	0.001289	0.000001	0.001288	0.002945	0	92
48.12	0.251029	0.25	0.25	0.036751	0.001290	0.000003	0.001286	0.004415	0	88
48.16	0.250823	0.25	0.25	0.03666	0.001291	0.000008	0.001283	0.005882	0	84
48.20	0.250558	0.25	0.25	0.036533	0.001292	0.000014	0.001279	0.007343	0	80
48.24	0.250236	0.25	0.25	0.036371	0.001295	0.000022	0.001273	0.008798	0	76
48.28	0.249855	0.25	0.25	0.036174	0.001297	0.000031	0.001266	0.010245	0	72
48.32	0.249416	0.25	0.25	0.035944	0.001300	0.000042	0.001258	0.011682	0	68
46.36	0.24892	0.25	0.25	0.035681	0.001303	0.000055	0.001249	0.013110	0	64
48.40	0.248368	0.25	0.25	0.035388	0.001307	0.000069	0.001239	0.014525	0	60
48.44	0.247759	0.25	0.25	0.035064	0.001312	0.000084	0.001227	0.015928	0	56
48.48	0.247094	0.25	0.25	0.034713	0.001316	0.000101	0.001215	0.017316	0	52
48.52	0.246374	0.25	0.25	0.034334	0.001322	0.000120	0.001202	0.018690	0	48
48.56	0.245599	0.25	0.25	0.033931	0.001327	0.000140	0.001188	0.020047	0	44
48.60	0.24477	0.25	0.25	0.033505	0.001333	0.000161	0.001173	0.021387	0	40
48.64	0.243888	0.25	0.25	0.033058	0.001340	0.000183	0.001157	0.022709	0	36
48.68	0.242954	0.25	0.25	0.032591	0.001347	0.000206	0.001141	0.024013	0	32
46.72	0.241968	0.25	0.25	0.032108	0.001354	0.000231	0.001124	0.025297	0	28

48.76	0.24093	0.25	0.25	0.031608	0.001362	0.000256	0.001106	0.026562	0	24
48.80	0.239843	0.25	0.25	0.031096	0.001371	0.000282	0.001088	0.027806	0	20
48.84	0.238706	0.25	0.25	0.030572	0.001379	0.000309	0.001070	0.029028	0	16
48.88	0.237521	0.25	0.25	0.030039	0.001388	0.000337	0.001051	0.030230	0	12
48.92	0.236288	0.25	0.25	0.029499	0.001398	0.000366	0.001032	0.031410	0	8
48.96	0.235009	0.25	0.25	0.028952	0.001408	0.000395	0.001013	0.032568	0	4
49.00	0.233683	0.25	0.25	0.028402	0.001418	0.000424	0.000994	0.033704	0	0
54.04	0.233651	0.25	0.25	0.040832	0.001429	0.000000	0.001429	0.001633	0	96
54.08	0.233553	0.25	0.25	0.040809	0.001429	0.000001	0.001428	0.003266	0	92
54.12	0.23339	0.25	0.25	0.04074	0.001430	0.000004	0.001426	0.004895	0	88
54.16	0.233161	0.25	0.25	0.040626	0.001432	0.000010	0.001422	0.006520	0	84
54.20	0.232868	0.25	0.25	0.040468	0.001433	0.000017	0.001416	0.008139	0	80
54.24	0.23251	0.25	0.25	0.040265	0.001436	0.000026	0.001409	0.009750	0	76
54.28	0.232088	0.25	0.25	0.040019	0.001439	0.000038	0.001401	0.011350	0	72
54.32	0.231602	0.25	0.25	0.039731	0.001442	0.000052	0.001391	0.012940	0	68
54.36	0.231053	0.25	0.25	0.039403	0.001446	0.000067	0.001379	0.014516	0	64
54.40	0.230442	0.25	0.25	0.039037	0.001451	0.000084	0.001366	0.016077	0	60
54.44	0.229768	0.25	0.25	0.038634	0.001456	0.000103	0.001352	0.017623	0	56
54.48	0.229032	0.25	0.25	0.038197	0.001461	0.000124	0.001337	0.019150	0	52
54.52	0.228236	0.25	0.25	0.037727	0.001467	0.000147	0.001320	0.020660	0	48
54.56	0.22738	0.25	0.25	0.037228	0.001474	0.000171	0.001303	0.022149	0	44
54.60	0.226464	0.25	0.25	0.0367	0.001481	0.000196	0.001285	0.023617	0	40
54.64	0.225491	0.25	0.25	0.036148	0.001488	0.000223	0.001265	0.025063	0	36
54.68	0.22446	0.25	0.25	0.035573	0.001496	0.000251	0.001245	0.026486	0	32
54.72	0.223372	0.25	0.25	0.034977	0.001505	0.000281	0.001224	0.027885	0	28
54.76	0.22223	0.25	0.25	0.034365	0.001514	0.000311	0.001203	0.029259	0	24
54.80	0.221032	0.25	0.25	0.033737	0.001523	0.000342	0.001181	0.030609	0	20
54.84	0.219781	0.25	0.25	0.033097	0.001533	0.000375	0.001158	0.031933	0	16
54.88	0.218478	0.25	0.25	0.032447	0.001544	0.000408	0.001136	0.033230	0	12
54.92	0.217124	0.25	0.25	0.031789	0.001554	0.000442	0.001113	0.034502	0	8
54.96	0.215719	0.25	0.25	0.031125	0.001566	0.000476	0.001089	0.035747	0	4
55.00	0.214264	0.25	0.25	0.030459	0.001577	0.000511	0.001066	0.036965	0	0
60.04	0.214228	0.25	0.25	0.045407	0.001589	0.000000	0.001589	0.001816	0	96
60.08	0.214119	0.25	0.25	0.045378	0.001590	0.000001	0.001588	0.003631	0	92
60.12	0.213938	0.25	0.25	0.045291	0.001590	0.000005	0.001585	0.005443	0	88
60.16	0.213684	0.25	0.25	0.045146	0.001592	0.000012	0.001580	0.007249	0	84
60.20	0.213358	0.25	0.25	0.044944	0.001594	0.000021	0.001573	0.009047	0	80
60.24	0.21296	0.25	0.25	0.044686	0.001597	0.000033	0.001564	0.010834	0	76
60.28	0.212491	0.25	0.25	0.044374	0.001600	0.000047	0.001553	0.012609	0	72
60.32	0.211952	0.25	0.25	0.04401	0.001604	0.000064	0.001540	0.014369	0	68
60.36	0.211342	0.25	0.25	0.043595	0.001608	0.000083	0.001526	0.016113	0	64
60.40	0.210663	0.25	0.25	0.043131	0.001613	0.000104	0.001510	0.017838	0	60
60.44	0.209915	0.25	0.25	0.042622	0.001619	0.000127	0.001492	0.019543	0	56
60.48	0.2091	0.25	0.25	0.042071	0.001625	0.000153	0.001472	0.021226	0	52
60.52	0.208218	0.25	0.25	0.041479	0.001632	0.000180	0.001452	0.022885	0	48

60.56	0.20727	0.25	0.25	0.040851	0.001639	0.000209	0.001430	0.024519	0	44
60.60	0.206257	0.25	0.25	0.040189	0.001647	0.000240	0.001407	0.026127	0	40
60.64	0.20518	0.25	0.25	0.039496	0.001655	0.000273	0.001382	0.027707	0	36
60.66	0.204041	0.25	0.25	0.038777	0.001664	0.000307	0.001357	0.029256	0	32
60.72	0.20284	0.25	0.25	0.038034	0.001674	0.000342	0.001331	0.030779	0	28
60.76	0.201579	0.25	0.25	0.037271	0.001683	0.000379	0.001304	0.032270	0	24
60.80	0.200259	0.25	0.25	0.036491	0.001694	0.000417	0.001277	0.033730	0	20
60.84	0.198881	0.25	0.25	0.035697	0.001704	0.000455	0.001249	0.035158	0	16
60.68	0.197447	0.25	0.25	0.034892	0.001716	0.000494	0.001221	0.036553	0	12
60.92	0.195958	0.25	0.25	0.034079	0.001727	0.000534	0.001193	0.037916	0	8
60.96	0.194415	0.25	0.25	0.033261	0.001739	0.000575	0.001164	0.039247	0	4
61.00	0.192819	0.25	0.25	0.03244	0.001752	0.000616	0.001135	0.040544	0	0
66.04	0.192778	0.25	0.25	0.050405	0.001764	0.000000	0.001764	0.002016	0	90
66.08	0.192657	0.25	0.25	0.050368	0.001765	0.000002	0.001763	0.004031	0	86
66.12	0.192456	0.25	0.25	0.050256	0.001765	0.000006	0.001759	0.006041	0	82
66.16	0.192174	0.25	0.25	0.05007	0.001767	0.000015	0.001752	0.008044	0	78
66.20	0.191813	0.25	0.25	0.049811	0.001769	0.000026	0.001743	0.010036	0	74
66.24	0.191372	0.25	0.25	0.049481	0.001772	0.000040	0.001732	0.012016	0	70
66.28	0.190852	0.25	0.25	0.049082	0.001776	0.000058	0.001718	0.013979	0	66
66.32	0.190254	0.25	0.25	0.048615	0.001780	0.000078	0.001702	0.015924	0	62
66.36	0.189578	0.25	0.25	0.048084	0.001784	0.000101	0.001683	0.017847	0	58
66.40	0.188826	0.25	0.25	0.047492	0.001790	0.000127	0.001662	0.019747	0	54
66.44	0.187999	0.25	0.25	0.046843	0.001795	0.000156	0.001640	0.021620	0	50
66.48	0.187097	0.25	0.25	0.046141	0.001802	0.000187	0.001615	0.023466	0	46
66.52	0.186122	0.25	0.25	0.045388	0.001809	0.000220	0.001589	0.025281	0	42
66.56	0.185075	0.25	0.25	0.04459	0.001816	0.000256	0.001561	0.027065	0	38
66.60	0.183958	0.25	0.25	0.043751	0.001824	0.000293	0.001531	0.028815	0	34
66.64	0.182771	0.25	0.25	0.042875	0.001833	0.000332	0.001501	0.030530	0	30
66.68	0.181516	0.25	0.25	0.041966	0.001842	0.000373	0.001469	0.032209	0	26
66.72	0.180195	0.25	0.25	0.041029	0.001851	0.000415	0.001436	0.033850	0	22
66.76	0.178809	0.25	0.25	0.040068	0.001861	0.000458	0.001402	0.035453	0	18
66.60	0.17736	0.25	0.25	0.039087	0.001871	0.000503	0.001368	0.037016	0	14
66.84	0.175848	0.25	0.25	0.03809	0.001881	0.000548	0.001333	0.038540	0	10
66.88	0.174277	0.25	0.25	0.037081	0.001892	0.000594	0.001298	0.040023	0	6
66.92	0.172647	0.25	0.25	0.036063	0.001903	0.000641	0.001262	0.041466	0	2
66.96	0.170961	0.25	0.25	0.03504	0.001914	0.000688	0.001226	0.042867	0	-2
67.00	0.170961	0.25	0.25	0.03504	0.001914	0.000688	0.001226	0.042867	0	-2
72.04	0.170917	0.25	0.25	0.055015	0.001926	0.000000	0.001926	0.002201	0	68
72.08	0.170785	0.25	0.25	0.054968	0.001926	0.000002	0.001924	0.004399	0	64
72.12	0.170565	0.25	0.25	0.054828	0.001927	0.000008	0.001919	0.006592	0	60
72.16	0.170258	0.25	0.25	0.054594	0.001928	0.000017	0.001911	0.008776	0	56
72.20	0.169863	0.25	0.25	0.054269	0.001930	0.000031	0.001899	0.010947	0	52
72.24	0.169382	0.25	0.25	0.053854	0.001933	0.000048	0.001885	0.013101	0	48
72.28	0.168815	0.25	0.25	0.053352	0.001936	0.000069	0.001867	0.015235	0	44
72.32	0.168164	0.25	0.25	0.052767	0.001940	0.000093	0.001847	0.017346	0	40

72.36	0.167428	0.25	0.25	0.052101	0.001944	0.000120	0.001824	0.019430	0	36
72.40	0.16661	0.25	0.25	0.05136	0.001949	0.000151	0.001798	0.021484	0	32
72.44	0.16571	0.25	0.25	0.050548	0.001954	0.000185	0.001769	0.023506	0	28
72.48	0.16473	0.25	0.25	0.049669	0.001959	0.000221	0.001738	0.025493	0	24
72.52	0.163671	0.25	0.25	0.04873	0.001965	0.000260	0.001706	0.027442	0	20
72.56	0.162536	0.25	0.25	0.047734	0.001972	0.000301	0.001671	0.029352	0	16
72.60	0.161324	0.25	0.25	0.046689	0.001979	0.000345	0.001634	0.031219	0	12
72.64	0.160039	0.25	0.25	0.045598	0.001986	0.000390	0.001596	0.033043	0	8
72.68	0.158682	0.25	0.25	0.044469	0.001993	0.000437	0.001556	0.034822	0	4
72.72	0.157254	0.25	0.25	0.043305	0.002001	0.000485	0.001516	0.036554	0	0
72.76	0.157254	0.25	0.25	0.043305	0.002001	0.000485	0.001516	0.036554	0	0
72.80	0.157254	0.25	0.25	0.043305	0.002001	0.000485	0.001516	0.036554	0	0
72.84	0.157254	0.25	0.25	0.043305	0.002001	0.000485	0.001516	0.036554	0	0
72.88	0.157254	0.25	0.25	0.043305	0.002001	0.000485	0.001516	0.036554	0	0
72.92	0.157254	0.25	0.25	0.043305	0.002001	0.000485	0.001516	0.036554	0	0
72.96	0.157254	0.25	0.25	0.043305	0.002001	0.000485	0.001516	0.036554	0	0
73.00	0.157254	0.25	0.25	0.043305	0.002001	0.000485	0.001518	0.036554	0	0
78.04	0.157208	0.25	0.25	0.057384	0.002008	0.000000	0.002008	0.002295	0	55
78.08	0.157071	0.25	0.25	0.057331	0.002009	0.000002	0.002007	0.004589	0	51
78.12	0.156841	0.25	0.25	0.057171	0.002009	0.000008	0.002001	0.006875	0	47
78.16	0.156521	0.25	0.25	0.056906	0.002011	0.000019	0.001992	0.009152	0	43
78.20	0.156109	0.25	0.25	0.056537	0.002012	0.000034	0.001979	0.011413	0	39
78.24	0.155608	0.25	0.25	0.056067	0.002014	0.000052	0.001962	0.013656	0	35
78.26	0.155017	0.25	0.25	0.055499	0.002017	0.000075	0.001942	0.015876	0	31
78.32	0.154338	0.25	0.25	0.054836	0.002020	0.000101	0.001919	0.018069	0	27
78.36	0.153572	0.25	0.25	0.054082	0.002023	0.000131	0.001893	0.020232	0	23
78.40	0.152721	0.25	0.25	0.053243	0.002027	0.000164	0.001864	0.022362	0	19
78.44	0.151784	0.25	0.25	0.052324	0.002031	0.000200	0.001831	0.024455	0	15
78.48	0.150765	0.25	0.25	0.05133	0.002036	0.000239	0.001797	0.026508	0	11
78.52	0.149664	0.25	0.25	0.050267	0.002040	0.000281	0.001759	0.028519	0	7
78.56	0.148484	0.25	0.25	0.049143	0.002045	0.000325	0.001720	0.030485	0	3
78.60	0.147227	0.25	0.25	0.047961	0.002050	0.000372	0.001679	0.032403	0	-1
78.64	0.147227	0.25	0.25	0.047961	0.002050	0.000372	0.001679	0.032403	0	-1
78.68	0.147227	0.25	0.25	0.047961	0.002050	0.000372	0.001679	0.032403	0	-1
78.72	0.147227	0.25	0.25	0.047961	0.002050	0.000372	0.001679	0.032403	0	-1
78.76	0.147227	0.25	0.25	0.047961	0.002050	0.000372	0.001679	0.032403	0	-1
78.80	0.147227	0.25	0.25	0.047961	0.002050	0.000372	0.001679	0.032403	0	-1
78.84	0.147227	0.25	0.25	0.047961	0.002050	0.000372	0.001679	0.032403	0	-1
78.88	0.147227	0.25	0.25	0.047961	0.002050	0.000372	0.001679	0.032403	0	-1
78.92	0.147227	0.25	0.25	0.047961	0.002050	0.000372	0.001679	0.032403	0	-1
78.96	0.147227	0.25	0.25	0.047961	0.002050	0.000372	0.001679	0.032403	0	-1
79.00	0.147227	0.25	0.25	0.047961	0.002050	0.000372	0.001679	0.032403	0	-1
84.04	0.14718	0.25	0.25	0.05873	0.002056	0.000000	0.002056	0.002349	0	45
84.08	0.147039	0.25	0.25	0.058672	0.002056	0.000002	0.002054	0.004696	0	41
84.12	0.146804	0.25	0.25	0.058499	0.002056	0.000009	0.002047	0.007036	0	37

84.16	0.146476	0.25	0.25	0.058212	0.002057	0.000020	0.002037	0.009365	0	33
84.20	0.146055	0.25	0.25	0.057812	0.002059	0.000035	0.002023	0.011677	0	29
84.24	0.145542	0.25	0.25	0.057303	0.002060	0.000055	0.002006	0.013969	0	25
84.28	0.144938	0.25	0.25	0.056687	0.002062	0.000078	0.001984	0.016237	0	21
84.32	0.144244	0.25	0.25	0.055968	0.002064	0.000105	0.001959	0.018475	0	17
84.36	0.143461	0.25	0.25	0.055152	0.002067	0.000137	0.001930	0.020681	0	13
64.40	0.14259	0.25	0.25	0.054243	0.002070	0.000171	0.001899	0.022851	0	9
64.44	0.141633	0.25	0.25	0.053247	0.002073	0.000209	0.001864	0.024981	0	5
84.46	0.140593	0.25	0.25	0.052171	0.002076	0.000250	0.001826	0.027068	0	1
84.52	0.139469	0.25	0.25	0.051021	0.002079	0.000293	0.001786	0.029109	0	-3
84.56	0.139469	0.25	0.25	0.051021	0.002079	0.000293	0.001786	0.029109	0	-3
84.60	0.139469	0.25	0.25	0.051021	0.002079	0.000293	0.001786	0.029109	0	-3
84.64	0.139469	0.25	0.25	0.051021	0.002079	0.000293	0.001786	0.029109	0	-3
84.68	0.139469	0.25	0.25	0.051021	0.002079	0.000293	0.001786	0.029109	0	-3
84.72	0.139469	0.25	0.25	0.051021	0.002079	0.000293	0.001786	0.029109	0	-3
84.76	0.139469	0.25	0.25	0.051021	0.002079	0.000293	0.001786	0.029109	0	-3
84.80	0.139469	0.25	0.25	0.051021	0.002079	0.000293	0.001786	0.029109	0	-3
84.84	0.139469	0.25	0.25	0.051021	0.002079	0.000293	0.001786	0.029109	0	-3
84.88	0.139469	0.25	0.25	0.051021	0.002079	0.000293	0.001786	0.029109	0	-3
84.92	0.139469	0.25	0.25	0.051021	0.002079	0.000293	0.001786	0.029109	0	-3
84.96	0.139469	0.25	0.25	0.051021	0.002079	0.000293	0.001786	0.029109	0	-3
85.00	0.139469	0.25	0.25	0.051021	0.002079	0.000293	0.001786	0.029109	0	-3
90.04	0.139421	0.25	0.25	0.059487	0.002082	0.000000	0.002082	0.002379	0	37
90.06	0.139279	0.25	0.25	0.059426	0.002082	0.000002	0.002080	0.004757	0	33
90.12	0.139041	0.25	0.25	0.059243	0.002083	0.000009	0.002074	0.007126	0	29
90.16	0.138709	0.25	0.25	0.05894	0.002083	0.000020	0.002063	0.009484	0	25
90.20	0.138283	0.25	0.25	0.058518	0.002084	0.000036	0.002048	0.011825	0	21
90.24	0.137763	0.25	0.25	0.05798	0.002085	0.000056	0.002029	0.014144	0	17
90.28	0.137152	0.25	0.25	0.057329	0.002087	0.000080	0.002007	0.016437	0	13
90.32	0.136449	0.25	0.25	0.056571	0.002088	0.000108	0.001980	0.018700	0	9
90.36	0.135656	0.25	0.25	0.055709	0.002090	0.000140	0.001950	0.020928	0	5
90.40	0.134775	0.25	0.25	0.054749	0.002091	0.000175	0.001916	0.023118	0	1
90.44	0.133808	0.25	0.25	0.053698	0.002093	0.000214	0.001879	0.025266	0	-3
90.48	0.133808	0.25	0.25	0.053698	0.002093	0.000214	0.001879	0.025266	0	-3
90.52	0.133808	0.25	0.25	0.053698	0.002093	0.000214	0.001879	0.025266	0	-3
90.56	0.133808	0.25	0.25	0.053698	0.002093	0.000214	0.001679	0.025266	0	-3
90.60	0.133808	0.25	0.25	0.053698	0.002093	0.000214	0.001879	0.025266	0	-3
90.64	0.133808	0.25	0.25	0.053698	0.002093	0.000214	0.001879	0.025266	0	-3
90.68	0.133808	0.25	0.25	0.053698	0.002093	0.000214	0.001879	0.025266	0	-3
90.72	0.133808	0.25	0.25	0.053698	0.002093	0.000214	0.001879	0.025266	0	-3
90.76	0.133808	0.25	0.25	0.053698	0.002093	0.000214	0.001879	0.025266	0	-3
90.80	0.133808	0.25	0.25	0.053698	0.002093	0.000214	0.001879	0.025266	0	-3
90.84	0.133808	0.25	0.25	0.053698	0.002093	0.000214	0.001879	0.025266	0	-3
90.88	0.133808	0.25	0.25	0.053698	0.002093	0.000214	0.001879	0.025266	0	-3
90.92	0.133808	0.25	0.25	0.053698	0.002093	0.000214	0.001879	0.025266	0	-3

90.96	0.133808	0.25	0.25	0.053698	0.002093	0.000214	0.001879	0.025266	0	-3
91.00	0.133808	0.25	0.25	0.053698	0.002093	0.000214	0.001879	0.025266	0	-3
96.04	0.13376	0.25	0.25	0.059857	0.002095	0.000000	0.002095	0.002394	0	31
96.08	0.133616	0.25	0.25	0.059794	0.002095	0.000002	0.002093	0.004786	0	27
96.12	0.133377	0.25	0.25	0.059605	0.002095	0.000009	0.002086	0.007170	0	23
96.16	0.133043	0.25	0.25	0.059291	0.002096	0.000021	0.002075	0.009542	0	19
96.20	0.132614	0.25	0.25	0.058854	0.002096	0.000036	0.002060	0.011896	0	15
96.24	0.132092	0.25	0.25	0.058297	0.002097	0.000057	0.002040	0.014228	0	11
96.28	0.131476	0.25	0.25	0.057623	0.002098	0.000081	0.002017	0.016533	0	7
96.32	0.13077	0.25	0.25	0.056837	0.002099	0.000109	0.001989	0.018806	0	3
96.36	0.129973	0.25	0.25	0.055944	0.002100	0.000141	0.001958	0.021044	0	-1
96.40	0.129973	0.25	0.25	0.055944	0.002100	0.000141	0.001958	0.021044	0	-1
96.44	0.129973	0.25	0.25	0.055944	0.002100	0.000141	0.001958	0.021044	0	-1
96.48	0.129973	0.25	0.25	0.055944	0.002100	0.000141	0.001958	0.021044	0	-1
96.52	0.129973	0.25	0.25	0.055944	0.002100	0.000141	0.001958	0.021044	0	-1
96.56	0.129973	0.25	0.25	0.055944	0.002100	0.000141	0.001958	0.021044	0	-1
96.60	0.129973	0.25	0.25	0.055944	0.002100	0.000141	0.001958	0.021044	0	-1
96.64	0.129973	0.25	0.25	0.055944	0.002100	0.000141	0.001958	0.021044	0	-1
96.68	0.129973	0.25	0.25	0.055944	0.002100	0.000141	0.001958	0.021044	0	-1
96.72	0.129973	0.25	0.25	0.055944	0.002100	0.000141	0.001958	0.021044	0	-1
96.76	0.129973	0.25	0.25	0.055944	0.002100	0.000141	0.001958	0.021044	0	-1
96.80	0.129973	0.25	0.25	0.055944	0.002100	0.000141	0.001958	0.021044	0	-1
96.84	0.129973	0.25	0.25	0.055944	0.002100	0.000141	0.001958	0.021044	0	-1
96.88	0.129973	0.25	0.25	0.055944	0.002100	0.000141	0.001958	0.021044	0	-1
96.92	0.129973	0.25	0.25	0.055944	0.002100	0.000141	0.001958	0.021044	0	-1
96.96	0.129973	0.25	0.25	0.055944	0.002100	0.000141	0.001958	0.021044	0	-1
97.00	0.129973	0.25	0.25	0.055944	0.002100	0.000141	0.001958	0.021044	0	-1
102.04	0.129925	0.25	0.25	0.060012	0.002100	0.000000	0.002100	0.002400	0	27
102.08	0.129781	0.25	0.25	0.059947	0.002100	0.000002	0.002098	0.004798	0	23
102.12	0.129541	0.25	0.25	0.059754	0.002101	0.000009	0.002091	0.007189	0	19
102.16	0.129206	0.25	0.25	0.059433	0.002101	0.000021	0.002080	0.009566	0	15
102.20	0.128776	0.25	0.25	0.058987	0.002101	0.000037	0.002065	0.011925	0	11
102.24	0.128252	0.25	0.25	0.058418	0.002101	0.000057	0.002045	0.014262	0	7
102.28	0.127636	0.25	0.25	0.057729	0.002102	0.000081	0.002021	0.016571	0	3
102.32	0.126927	0.25	0.25	0.056926	0.002102	0.000110	0.001992	0.018848	0	-1
102.36	0.126927	0.25	0.25	0.056926	0.002102	0.000110	0.001992	0.018848	0	-1
102.40	0.126927	0.25	0.25	0.056926	0.002102	0.000110	0.001992	0.018848	0	-1
102.44	0.126927	0.25	0.25	0.056926	0.002102	0.000110	0.001992	0.018848	0	-1
102.48	0.126927	0.25	0.25	0.056926	0.002102	0.000110	0.001992	0.018848	0	-1
102.52	0.126927	0.25	0.25	0.056926	0.002102	0.000110	0.001992	0.018848	0	-1
102.56	0.126927	0.25	0.25	0.056926	0.002102	0.000110	0.001992	0.018848	0	-1
102.60	0.126927	0.25	0.25	0.056926	0.002102	0.000110	0.001992	0.018848	0	-1
102.64	0.126927	0.25	0.25	0.056926	0.002102	0.000110	0.001992	0.018848	0	-1
102.68	0.126927	0.25	0.25	0.056926	0.002102	0.000110	0.001992	0.018848	0	-1
102.72	0.126927	0.25	0.25	0.056926	0.002102	0.000110	0.001992	0.018848	0	-1

102.76	0.126927	0.25	0.25	0.056926	0.002102	0.000110	0.001992	0.018848	0	-1
102.80	0.126927	0.25	0.25	0.056926	0.002102	0.000110	0.001992	0.018848	0	-1
102.84	0.126927	0.25	0.25	0.056926	0.002102	0.000110	0.001992	0.018848	0	-1
102.88	0.126927	0.25	0.25	0.056926	0.002102	0.000110	0.001992	0.018848	0	-1
102.92	0.126927	0.25	0.25	0.056926	0.002102	0.000110	0.001992	0.018848	0	-1
102.96	0.126927	0.25	0.25	0.056926	0.002102	0.000110	0.001992	0.018848	0	-1
103.00	0.126927	0.25	0.25	0.056926	0.002102	0.000110	0.001992	0.018848	0	-1
108.04	0.126879	0.25	0.25	0.060075	0.002103	0.000000	0.002103	0.002403	0	24
108.08	0.126735	0.25	0.25	0.060009	0.002103	0.000002	0.002100	0.004803	0	20
108.12	0.126495	0.25	0.25	0.059813	0.002103	0.000009	0.002093	0.007196	0	16
108.16	0.12616	0.25	0.25	0.059487	0.002103	0.000021	0.002082	0.009575	0	12
108.20	0.125729	0.25	0.25	0.059034	0.002103	0.000037	0.002066	0.011937	0	8
108.24	0.125205	0.25	0.25	0.058456	0.002103	0.000057	0.002046	0.014275	0	4
108.28	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
108.32	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
108.36	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
108.40	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
108.44	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
108.48	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
108.52	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
108.56	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
108.60	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
108.64	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
108.68	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
108.72	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
108.76	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
108.80	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
108.84	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
108.88	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
108.92	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
108.96	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
109.00	0.124588	0.25	0.25	0.057757	0.002103	0.000082	0.002021	0.016585	0	0
114.04	0.12454	0.25	0.25	0.060085	0.002103	0.000000	0.002103	0.002403	0	22
114.08	0.124396	0.25	0.25	0.060019	0.002103	0.000002	0.002101	0.004804	0	18
114.12	0.124156	0.25	0.25	0.059821	0.002103	0.000009	0.002094	0.007197	0	14
114.16	0.12382	0.25	0.25	0.059492	0.002103	0.000021	0.002082	0.009577	0	10
114.20	0.12339	0.25	0.25	0.059033	0.002103	0.000037	0.002066	0.011938	0	6
114.24	0.122866	0.25	0.25	0.058449	0.002103	0.000057	0.002046	0.014276	0	2
114.28	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.016586	0	-2
114.32	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.016586	0	-2
114.36	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.016586	0	-2
114.40	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.016586	0	-2
114.44	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.016586	0	-2
114.48	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.016586	0	-2
114.52	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.016586	0	-2

114.56	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.018586	0	-2
114.60	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.016586	0	-2
114.64	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.016586	0	-2
114.68	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.016586	0	-2
114.72	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.016586	0	-2
114.76	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.016586	0	-2
114.80	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.016586	0	-2
114.84	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.016586	0	-2
114.88	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.016586	0	-2
114.92	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.016586	0	-2
114.96	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.016586	0	-2
115.00	0.122248	0.25	0.25	0.057743	0.002103	0.000082	0.002021	0.016586	0	-2
120.04	0.1222	0.25	0.25	0.060062	0.002102	0.000000	0.002102	0.002402	0	20
120.08	0.122056	0.25	0.25	0.059995	0.002102	0.000002	0.002100	0.004802	0	16
120.12	0.121816	0.25	0.25	0.059795	0.002102	0.000009	0.002093	0.007194	0	12
120.16	0.121481	0.25	0.25	0.059463	0.002102	0.000021	0.002081	0.009573	0	8
120.20	0.121051	0.25	0.25	0.059	0.002102	0.000037	0.002065	0.011933	0	4
120.24	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
120.28	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
120.32	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
120.36	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
120.40	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
120.44	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
120.48	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
120.52	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
120.56	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
120.60	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
120.64	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
120.68	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
120.72	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
120.76	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
120.80	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
120.84	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
120.88	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
120.92	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
120.96	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
121.00	0.120527	0.25	0.25	0.05841	0.002101	0.000057	0.002044	0.014269	0	0
126.04	0.120479	0.25	0.25	0.060023	0.002101	0.000000	0.002101	0.002401	0	18
126.08	0.120335	0.25	0.25	0.059956	0.002101	0.000002	0.002098	0.004799	0	14
126.12	0.120095	0.25	0.25	0.059754	0.002101	0.000009	0.002091	0.007189	0	10
126.16	0.11976	0.25	0.25	0.059419	0.002100	0.000021	0.002080	0.009566	0	6
126.20	0.11933	0.25	0.25	0.058953	0.002100	0.000037	0.002063	0.011924	0	2
126.24	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
126.28	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
126.32	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2

126.36	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
126.40	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
126.44	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
126.48	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
126.52	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
126.56	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
126.60	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
126.64	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
126.68	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
126.72	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
126.76	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
126.80	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
126.84	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
126.88	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
126.92	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
126.96	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
127.00	0.118806	0.25	0.25	0.058359	0.002099	0.000057	0.002043	0.014259	0	-2
132.04	0.118758	0.25	0.25	0.059964	0.002099	0.000000	0.002099	0.002399	0	16
132.08	0.118615	0.25	0.25	0.059897	0.002099	0.000002	0.002096	0.004794	0	12
132.12	0.118375	0.25	0.25	0.059694	0.002098	0.000009	0.002089	0.007182	0	8
132.16	0.11804	0.25	0.25	0.059357	0.002098	0.000021	0.002077	0.009556	0	4
132.20	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.24	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.28	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.32	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.36	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.40	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.44	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.48	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.52	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.56	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.60	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.64	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.68	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.72	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.76	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.80	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.84	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.88	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.92	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
132.96	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
133.00	0.117611	0.25	0.25	0.058888	0.002098	0.000037	0.002061	0.011912	0	0
138.04	0.117563	0.25	0.25	0.059912	0.002097	0.000000	0.002097	0.002396	0	15
138.08	0.117419	0.25	0.25	0.059844	0.002097	0.000002	0.002095	0.004790	0	11
138.12	0.11718	0.25	0.25	0.05964	0.002097	0.000009	0.002087	0.007176	0	7

138.16	0.116845	0.25	0.25	0.059302	0.002096	0.000021	0.002076	0.009548	0	3
138.20	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.24	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.28	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.32	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.36	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.40	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.44	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.48	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.52	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.56	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.60	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.64	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.68	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.72	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.76	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.80	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.84	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.88	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.92	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
138.96	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
139.00	0.116416	0.25	0.25	0.058832	0.002096	0.000036	0.002059	0.011901	0	-1
144.04	0.116369	0.25	0.25	0.05985	0.002095	0.000000	0.002095	0.002394	0	14
144.08	0.116225	0.25	0.25	0.059782	0.002095	0.000002	0.002092	0.004785	0	10
144.12	0.115986	0.25	0.25	0.059577	0.002094	0.000009	0.002085	0.007168	0	6
144.16	0.115652	0.25	0.25	0.059238	0.002094	0.000021	0.002073	0.009538	0	2
144.20	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
144.24	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
144.28	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
144.32	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
144.36	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
144.40	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
144.44	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
144.48	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
144.52	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
144.56	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
144.60	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
144.64	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
144.68	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
144.72	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
144.76	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
144.80	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
144.84	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
144.88	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
144.92	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2

144.96	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
145.00	0.115223	0.25	0.25	0.058765	0.002093	0.000036	0.002057	0.011889	0	-2
150.04	0.115175	0.25	0.25	0.059778	0.002092	0.000000	0.002092	0.002391	0	13
150.08	0.115032	0.25	0.25	0.05971	0.002092	0.000002	0.002090	0.004780	0	9
150.12	0.114793	0.25	0.25	0.059505	0.002092	0.000009	0.002083	0.007160	0	5
150.16	0.11446	0.25	0.25	0.059164	0.002091	0.000021	0.002071	0.009526	0	1
150.20	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.24	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.28	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.32	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.36	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.40	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.44	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.48	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.52	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.56	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.60	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.64	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.68	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.72	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.76	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.80	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.84	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.88	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.92	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
150.96	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
151.00	0.114032	0.25	0.25	0.05869	0.002090	0.000036	0.002054	0.011874	0	-3
156.04	0.113984	0.25	0.25	0.059697	0.002089	0.000000	0.002089	0.002388	0	12
156.08	0.113841	0.25	0.25	0.059628	0.002089	0.000002	0.002087	0.004773	0	8
156.12	0.113602	0.25	0.25	0.059422	0.002089	0.000009	0.002080	0.007150	0	4
156.16	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0
156.20	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0
156.24	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0
156.28	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0
156.32	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0
156.36	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0
156.40	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0
156.44	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0
156.48	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0
156.52	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0
156.56	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0
156.60	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0
156.64	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0
156.68	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0
156.72	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0

156.76	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002088	0.009513	0	0
156.80	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0
156.84	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0
156.88	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0
156.92	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002088	0.009513	0	0
156.96	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0
157.00	0.113269	0.25	0.25	0.05908	0.002088	0.000020	0.002068	0.009513	0	0

Appendix F: Experiment 1 Data & Results

Table 12: 4 Factor-3 level, Full Factorial Design-Experiment 1

StdOrder	RunOrder	PtType	Blocks	Cycle Time	No. of Turns of Ext. Coil	Radius of Ext. Coil	Current in Ext. Coil	Response Time	Oscillations (Std. Dev)
1	1	1	1	1000	1000	250	2000	133.002	0.000908
2	2	1	1	1000	1000	250	4000	73.001	0.001901
3	3	1	1	1000	1000	250	6000	49.001	0.002853
4	4	1	1	1000	1000	300	2000	150.999	0.000702
5	5	1	1	1000	1000	300	4000	73.001	0.001398
6	6	1	1	1000	1000	300	6000	49.001	0.002295
7	7	1	1	1000	1000	350	2000	162.997	0.00056
8	8	1	1	1000	1000	350	4000	85.002	0.001107
9	9	1	1	1000	1000	350	6000	55.001	0.001719
10	10	1	1	1000	3000	250	2000	49.001	0.002853
11	11	1	1	1000	3000	250	4000	31	0.009017
12	12	1	1	1000	3000	250	6000	19	0.01918
13	13	1	1	1000	3000	300	2000	49.001	0.002295
14	14	1	1	1000	3000	300	4000	31	0.006897
15	15	1	1	1000	3000	300	6000	19	0.017732
16	16	1	1	1000	3000	350	2000	55.001	0.001719
17	17	1	1	1000	3000	350	4000	31	0.005438
18	18	1	1	1000	3000	350	6000	25	0.013431
19	19	1	1	1000	5000	250	2000	31	0.006506
20	20	1	1	1000	5000	250	4000	19	0.022414
21	21	1	1	1000	5000	250	6000	13	0.040113
22	22	1	1	1000	5000	300	2000	31	0.004579
23	23	1	1	1000	5000	300	4000	19	0.021662
24	24	1	1	1000	5000	300	6000	13	0.039725
25	25	1	1	1000	5000	350	2000	37	0.004312
26	26	1	1	1000	5000	350	4000	19	0.017809
27	27	1	1	1000	5000	350	6000	19	0.036715
28	28	1	1	2000	1000	250	2000	74.001	0.002936
29	29	1	1	2000	1000	250	4000	50.001	0.013267
30	30	1	1	2000	1000	250	6000	38	0.028546
31	31	1	1	2000	1000	300	2000	86.002	0.002255
32	32	1	1	2000	1000	300	4000	50.001	0.011488
33	33	1	1	2000	1000	300	6000	38	0.027918
34	34	1	1	2000	1000	350	2000	86.002	0.002005
35	35	1	1	2000	1000	350	4000	50.001	0.007051
36	36	1	1	2000	1000	350	6000	38	0.02349
37	37	1	1	2000	3000	250	2000	38	0.028546

38	38	1	1	2000	3000	250	4000	26	0.078405
39	39	1	1	2000	3000	250	6000	14	0.100882
40	40	1	1	2000	3000	300	2000	38	0.027918
41	41	1	1	2000	3000	300	4000	26	0.062254
42	42	1	1	2000	3000	300	6000	14	0.109778
43	43	1	1	2000	3000	350	2000	38	0.02349
44	44	1	1	2000	3000	350	4000	26	0.064014
45	45	1	1	2000	3000	350	6000	14	0.082491
46	46	1	1	2000	5000	250	2000	26	0.057585
47	47	1	1	2000	5000	250	4000	14	0.110724
48	48	1	1	2000	5000	250	6000	14	0.14022
49	49	1	1	2000	5000	300	2000	26	0.054151
50	50	1	1	2000	5000	300	4000	14	0.121574
51	51	1	1	2000	5000	300	6000	14	0.150238
52	52	1	1	2000	5000	350	2000	26	0.052099
53	53	1	1	2000	5000	350	4000	14	0.089305
54	54	1	1	2000	5000	350	6000	14	0.133161
55	55	1	1	3000	1000	250	2000	57.001	0.027029
56	56	1	1	3000	1000	250	4000	39.001	0.074691
57	57	1	1	3000	1000	250	6000	39.001	0.112704
58	58	1	1	3000	1000	300	2000	57.001	0.026388
59	59	1	1	3000	1000	300	4000	39.001	0.06137
60	60	1	1	3000	1000	300	6000	39.001	0.104258
61	61	1	1	3000	1000	350	2000	75.001	0.022018
62	62	1	1	3000	1000	350	4000	39.001	0.055855
63	63	1	1	3000	1000	350	6000	39.001	0.083679
64	64	1	1	3000	3000	250	2000	39.001	0.112704
65	65	1	1	3000	3000	250	4000	21	0.13014
66	66	1	1	3000	3000	250	6000	21	0.150435
67	67	1	1	3000	3000	300	2000	39.001	0.104258
68	68	1	1	3000	3000	300	4000	21	0.136341
69	69	1	1	3000	3000	300	6000	21	0.168493
70	70	1	1	3000	3000	350	2000	39.001	0.083679
71	71	1	1	3000	3000	350	4000	21	0.125711
72	72	1	1	3000	3000	350	6000	21	0.161724
73	73	1	1	3000	5000	250	2000	21	0.127086
74	74	1	1	3000	5000	250	4000	21	0.172318
75	75	1	1	3000	5000	250	6000	21	0.197126
76	76	1	1	3000	5000	300	2000	21	0.13408
77	77	1	1	3000	5000	300	4000	21	0.180938
78	78	1	1	3000	5000	300	6000	21	0.16461
79	79	1	1	3000	5000	350	2000	21	0.110875
80	80	1	1	3000	5000	350	4000	21	0.167389
81	81	1	1	3000	5000	350	6000	21	0.182995

Minitab out for Analysis of the Full Factorial Design (81 runs, 4 factor-3 level):

General Linear Model: Response Tim, Oscillations versus Cycle Time, No. of Turn

Factor	Type	Levels	Values
Cycle Time	fixed	3	1000, 2000, 3000
No. of Turns of Ext. Coil	fixed	3	1000, 3000, 5000
Radius of Ext. Coil	fixed	3	250, 300, 350
Current in Ext. Coil	fixed	3	2000, 4000, 6000

Analysis of Variance for Response Time, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cycle Time	2	5284.2	5284.2	2642.1	11.45	0.000
No. of Turns of Ext. Coil	2	30620.6	30620.6	15310.3	66.34	0.000
Radius of Ext. Coil	2	203.5	203.5	101.8	0.44	0.645
Current in Ext. Coil	2	13059.7	13059.7	6529.9	28.30	0.000
Error	72	16615.4	16615.4	230.8		
Total	80	65783.5				

S = 15.1911   R-Sq = 74.74%   R-Sq(adj) = 71.94%

Unusual Observations for Response Time

Obs	Response Time	Fit	SE Fit	Residual	St Resid	
1	133.002	92.556	5.064	40.446	2.82	R
4	150.999	93.668	5.064	57.331	4.00	R
7	162.997	96.334	5.064	66.663	4.65	R

R denotes an observation with a large standardized residual.

Analysis of Variance for Oscillations, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cycle Time	2	0.155391	0.155391	0.077696	179.04	0.000
No. of Turns of Ext. Coil	2	0.063774	0.063774	0.031887	73.48	0.000
Radius of Ext. Coil	2	0.001045	0.001045	0.000522	1.20	0.306
Current in Ext. Coil	2	0.030211	0.030211	0.015105	34.81	0.000
Error	72	0.031245	0.031245	0.000434		
Total	80	0.281666				

S = 0.0208317   R-Sq = 88.91%   R-Sq(adj) = 87.67%

Unusual Observations for Oscillations

Obs	Oscillations	Fit	SE Fit	Residual	St Resid	
1	0.000908	-0.047766	0.006944	0.048674	2.48	R

4	0.000702	-0.048710	0.006944	0.049412	2.52 R
7	0.000560	-0.055812	0.006944	0.056372	2.87 R

R denotes an observation with a large standardized residual.

Least Squares Means

	--Response Time-		--Oscillations-	
Cycle Time	Mean	SE Mean	Mean	SE Mean
1000	49.6670	2.92353	0.0106	0.00401
2000	33.5559	2.92353	0.0595	0.00401
3000	31.6671	2.92353	0.1177	0.00401
No. of Turns				
1000	65.3341	2.92353	0.0259	0.00401
3000	29.1113	2.92353	0.0678	0.00401
5000	20.4444	2.92353	0.0941	0.00401
Radius of Ex				
250	36.6671	2.92353	0.0656	0.00401
300	37.7781	2.92353	0.0647	0.00401
350	40.4447	2.92353	0.0575	0.00401
Current in E				
2000	55.7782	2.92353	0.0379	0.00401
4000	33.1115	2.92353	0.0648	0.00401
6000	26.0002	2.92353	0.0851	0.00401

Appendix G: Experiment 2 Data & Results

Table 13:Box-Behnken Design-Experiment 2

StdOrder	RunOrder	PtType	Blocks	Cycle Time	No. of turns of Ext. Coil	Current in Ext. Coil	Time	Std. Dev.
1	1	2	1	1000	1000	3000	90.0462	0.0014037
2	2	2	1	2000	1000	3000	60.041	0.0063653
3	3	2	1	1000	3000	3000	36.0404	0.0051228
4	4	2	1	2000	3000	3000	25.0802	0.0476329
5	5	2	1	1000	2000	2000	72.0413	0.0019011
6	6	2	1	2000	2000	2000	48.0407	0.0132449
7	7	2	1	1000	2000	4000	36.8005	0.0039272
8	8	2	1	2000	2000	4000	25.5202	0.0418794
9	9	2	1	1500	1000	2000	90.0406	0.0015414
10	10	2	1	1500	3000	2000	36.8512	0.017061
11	11	2	1	1500	1000	4000	54.0397	0.0064246
12	12	2	1	1500	3000	4000	27.0406	0.055205
13	13	0	1	1500	2000	3000	36.8512	0.017061
14	14	0	1	1500	2000	3000	36.8512	0.017061
15	15	0	1	1500	2000	3000	36.8512	0.017061

Minitab Output for Analysis of Box-Behnken design:

Response Surface Regression: Time versus Cycle Time, No. of turns, Current in E

```
The analysis was done using coded units.

Estimated Regression Coefficients for Time

Term                                   Coef  SE Coef        T      P
Constant                             36.851   1.4496   25.421  0.000
Cycle Time                           -9.531   0.8877  -10.736  0.000
No. of turns of Ext. Coil           -21.144   0.8877  -23.819  0.000
Current in Ext. Coil                -12.947   0.8877  -14.584  0.000
Cycle Time*Cycle Time                 4.779   1.3067    3.658  0.015
No. of turns of Ext. Coil*           11.172   1.3067    8.550  0.000
  No. of turns of Ext. Coil
Current in Ext. Coil*                 3.970   1.3067    3.038  0.029
  Current in Ext. Coil
Cycle Time*No. of turns of Ext. Coil  4.761   1.2554    3.793  0.013
Cycle Time*Current in Ext. Coil       3.180   1.2554    2.533  0.052
No. of turns of Ext. Coil*            6.548   1.2554    5.215  0.003
  Current in Ext. Coil

S = 2.511   R-Sq = 99.5%   R-Sq(adj) = 98.6%
```

Analysis of Variance for Time

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	6494.69	6494.69	721.63	114.47	0.000
Linear	3	5644.28	5644.28	1881.43	298.44	0.000
Square	3	547.80	547.80	182.60	28.96	0.001
Interaction	3	302.61	302.61	100.87	16.00	0.005
Residual Error	5	31.52	31.52	6.30		
Lack-of-Fit	3	31.52	31.52	10.51		
Pure Error	2	0.00	0.00	0.00		
Total	14	6526.21				

Unusual Observations for Time

Obs	StdOrder	Time	Fit	SE Fit	Residual	St Resid
9	9	90.041	92.632	2.174	-2.591	-2.06 R
12	12	27.041	24.450	2.174	2.591	2.06 R

R denotes an observation with a large standardized residual.

Estimated Regression Coefficients for Time using data in uncoded units

Term	Coef
Constant	366.477
Cycle Time	-0.114537
No. of turns of Ext. Coil	-0.0997569
Current in Ext. Coil	-0.0594035
Cycle Time*Cycle Time	1.91167E-05
No. of turns of Ext. Coil* No. of turns of Ext. Coil	1.11715E-05
Current in Ext. Coil* Current in Ext. Coil	3.97025E-06
Cycle Time*No. of turns of Ext. Coil	9.52247E-06
Cycle Time*Current in Ext. Coil	6.36015E-06
No. of turns of Ext. Coil* Current in Ext. Coil	6.54757E-06

Response Surface Regression: Std. Dev. versus Cycle Time, No. of turns, ...

The analysis was done using coded units.

Estimated Regression Coefficients for Std. Dev.

Term	Coef	SE Coef	T	P
Constant	0.017061	0.002100	8.124	0.000
Cycle Time	0.012096	0.001286	9.405	0.000
No. of turns of Ext. Coil	0.013661	0.001286	10.622	0.000
Current in Ext. Coil	0.009211	0.001286	7.162	0.001
Cycle Time*Cycle Time	-0.003375	0.001893	-1.783	0.135

No. of turns of Ext. Coil* No. of turns of Ext. Coil	0.001445	0.001893	0.763	0.480
Current in Ext. Coil* Current in Ext. Coil	0.001552	0.001893	0.820	0.450
Cycle Time*No. of turns of Ext. Coil	0.009387	0.001819	5.161	0.004
Cycle Time*Current in Ext. Coil	0.006652	0.001819	3.657	0.015
No. of turns of Ext. Coil* Current in Ext. Coil	0.008315	0.001819	4.572	0.006

S = 0.003638   R-Sq = 98.5%   R-Sq(adj) = 95.7%

Analysis of Variance for Std. Dev.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.004212	0.004212	0.000468	35.37	0.001
Linear	3	0.003342	0.003342	0.001114	84.20	0.000
Square	3	0.000064	0.000064	0.000021	1.60	0.301
Interaction	3	0.000806	0.000806	0.000269	20.31	0.003
Residual Error	5	0.000066	0.000066	0.000013		
Lack-of-Fit	3	0.000066	0.000066	0.000022		
Pure Error	2	0.000000	0.000000	0.000000		
Total	14	0.004278				

Unusual Observations for Std. Dev.

Obs	StdOrder	Std. Dev.	Fit	SE Fit	Residual	St Resid	
9	9	0.002	0.006	0.003	-0.004	-2.18	R
12	12	0.055	0.051	0.003	0.004	2.18	R

R denotes an observation with a large standardized residual.

Estimated Regression Coefficients for Std. Dev. using data in uncoded units

Term	Coef
Constant	0.0812758
Cycle Time	-1.27712E-05
No. of turns of Ext. Coil	-4.52262E-05
Current in Ext. Coil	-3.66876E-05
Cycle Time*Cycle Time	-1.34994E-08
No. of turns of Ext. Coil* No. of turns of Ext. Coil	1.44500E-09
Current in Ext. Coil* Current in Ext. Coil	1.55198E-09
Cycle Time*No. of turns of Ext. Coil	1.87743E-08
Cycle Time*Current in Ext. Coil	1.33042E-08
No. of turns of Ext. Coil* Current in Ext. Coil	8.31520E-09

Response Optimization Graph:

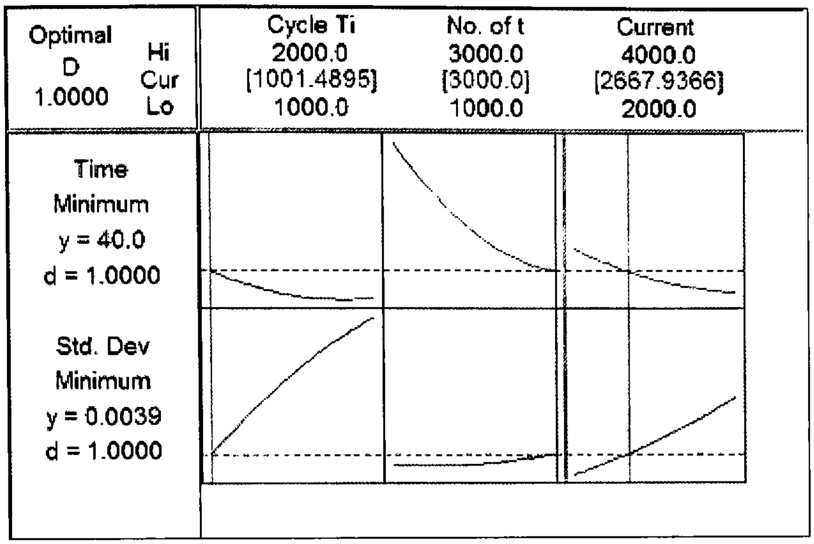


Figure 37: Response Optimization Graph